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ADVANCE WASTE TREATMENT AND WATER REUSE SYMPOSIUM HELD AT ADOLPHUS HOTEL, DALLAS, TEXAS ON JANUARY 12-14, 1971. SESSION 3

John Trugg, et al

Federal Water Quality Administration
Cincinnati, Ohio

1971

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ADVANCE WASTE TREATMENT AND WATER REUSE SYMPOSIUM

Adolphus Hotel

Dallas, Texas

January 12-14, 1971

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Session #3
Wednesday, January 13

Moderator: John Trygg, Director
Bureau of Environmental Health
Louisiana State Department of Health

9:00 A.M. Phosphorus Removal In Conventional Treatment
Edwin F. Barth

9:45 A.M. Combined Biological-Chemical Treatment For Phosphorus Control
Richard C. Brenner

10:30 A.M. Coffee Break

10:45 A.M. Modification Of A Trickling Filter Plant To Allow Chemical Precipitation
James Laughlin

11:15 A.M. Chemical Precipitation Of Phosphorus
Dr. S. A. Hannah

11:45 A.M. Summary
John Trygg

ADVANCED WASTE TREATMENT AND

WATER REUSE SYMPOSIUM

January 12-14, 1971

Dallas, Texas

PHOSPHORUS REMOVAL IN CONVENTIONAL TREATMENT

Edwin F. Barth
Advanced Waste Treatment Research Laboratory
U.S. Department of the Interior
Federal Water Quality Administration
Ohio Basin Region
Cincinnati, Ohio

PHOSPHORUS REMOVAL IN CONVENTIONAL TREATMENT

Only 60% of the population of the United States provides some type of treatment for its wastewater. Most conventional treatment systems are biological processes and these are generally inefficient in the removal of phosphorus. Annually in the United States about 400×10^6 pounds of phosphorus are discharged to receiving waters from these treatment plants. Another 200×10^6 pounds of phosphorus are discharged from individual home units or other unsewered sources.

Of the treatment processes employed in conventional systems the activated sludge process is most efficient in phosphorus removal because the efficiency of removal is directly related to solids production. Several activated sludge plants in various parts of the country have reported very efficient removals. Evaluation has indicated the operating parameters, at these particular sites, which influence phosphorus removal. In most cases these removals can be ascribed to interaction of the chemical characteristics of the carriage water and the biological process.

One key observation at these sites has been the fact that in a conventional system digester supernatant recycle has a great influence on phosphorus removal. Anaerobic digestion solubilizes the solids previously removed in the main stream and recycle of the supernatant adds large quantities of soluble phosphorus, organic matter, and nitrogenous material into the biological process.

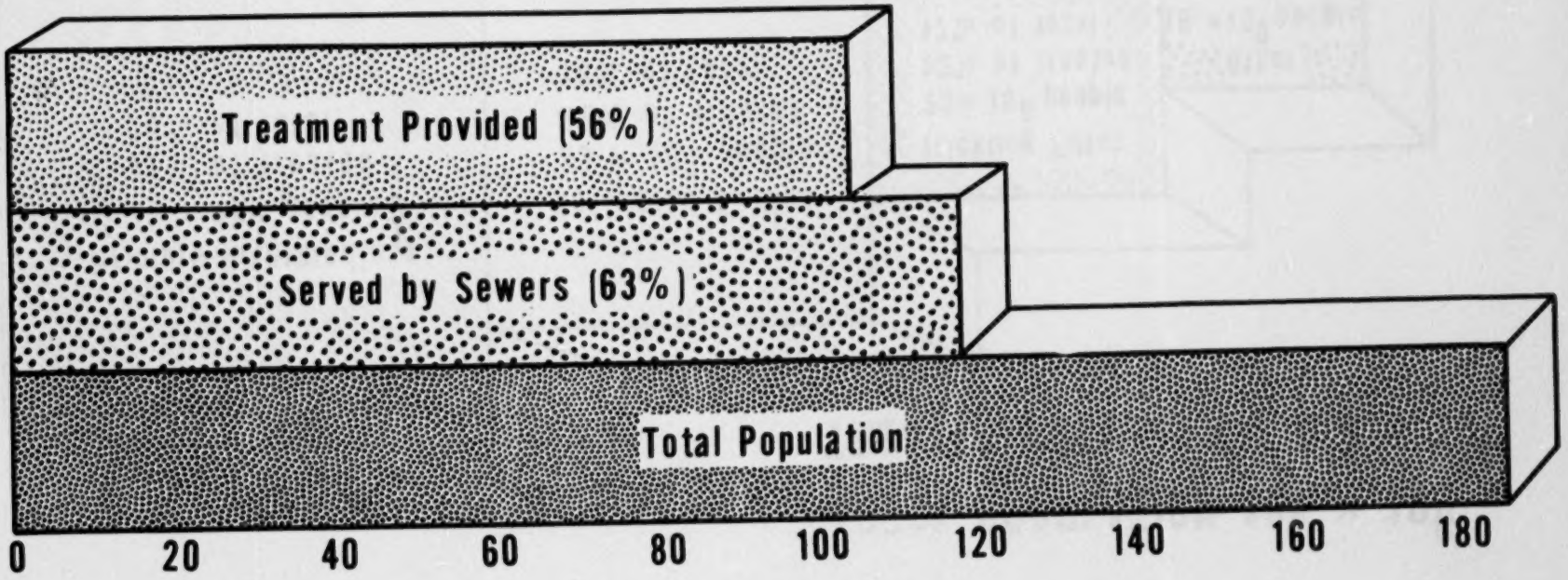
Aside from this nutrient loading aspect, digester supernatant introduces a high organic load and much colloidal material. A chemical-physical process has been developed which can effectively treat supernatant. Application of this process at treatment plants which are of marginal efficiency can up-grade the quality of the final effluent.

At those plants which are marginal we can do several things to increase nutrient removal efficiency and generally produce an overall improvement in effluent quality. Most marginal performance is due to four causes. These are hydraulic overload, organic overload, poor liquid-solids separation, and operator skill.

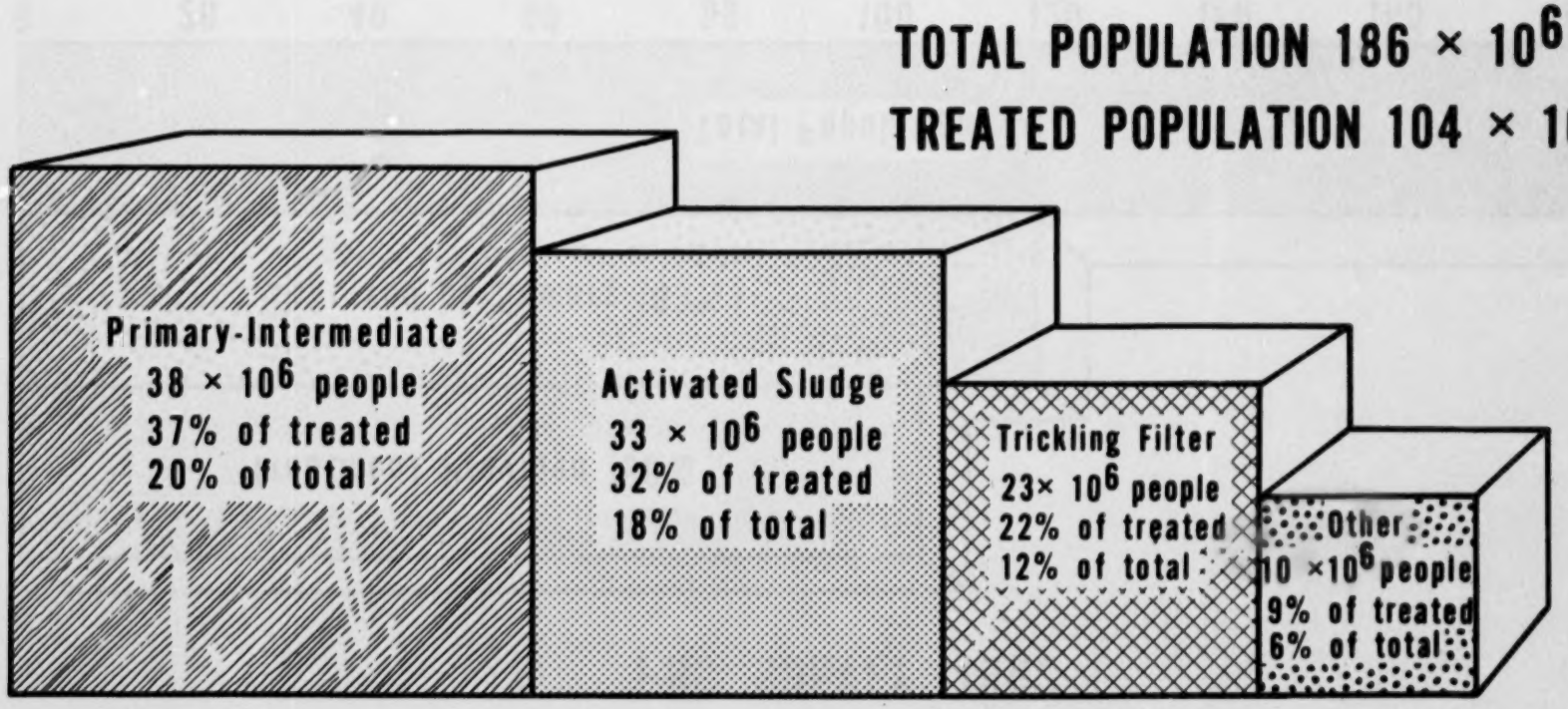
There is a large amount of capital investment in existing conventional secondary treatment facilities, and provision for efficient performance of these facilities can go a long way in meeting our water quality goals. Many of these units can be modified to improve removal of specific pollutants, such as phosphorus; or serve a useful function as a first step in an advanced process. Much of our past effort has been in the direction of reducing the cost of treatment, not in the direction of improved treatment. In many areas we have low cost treatment and low efficiency.

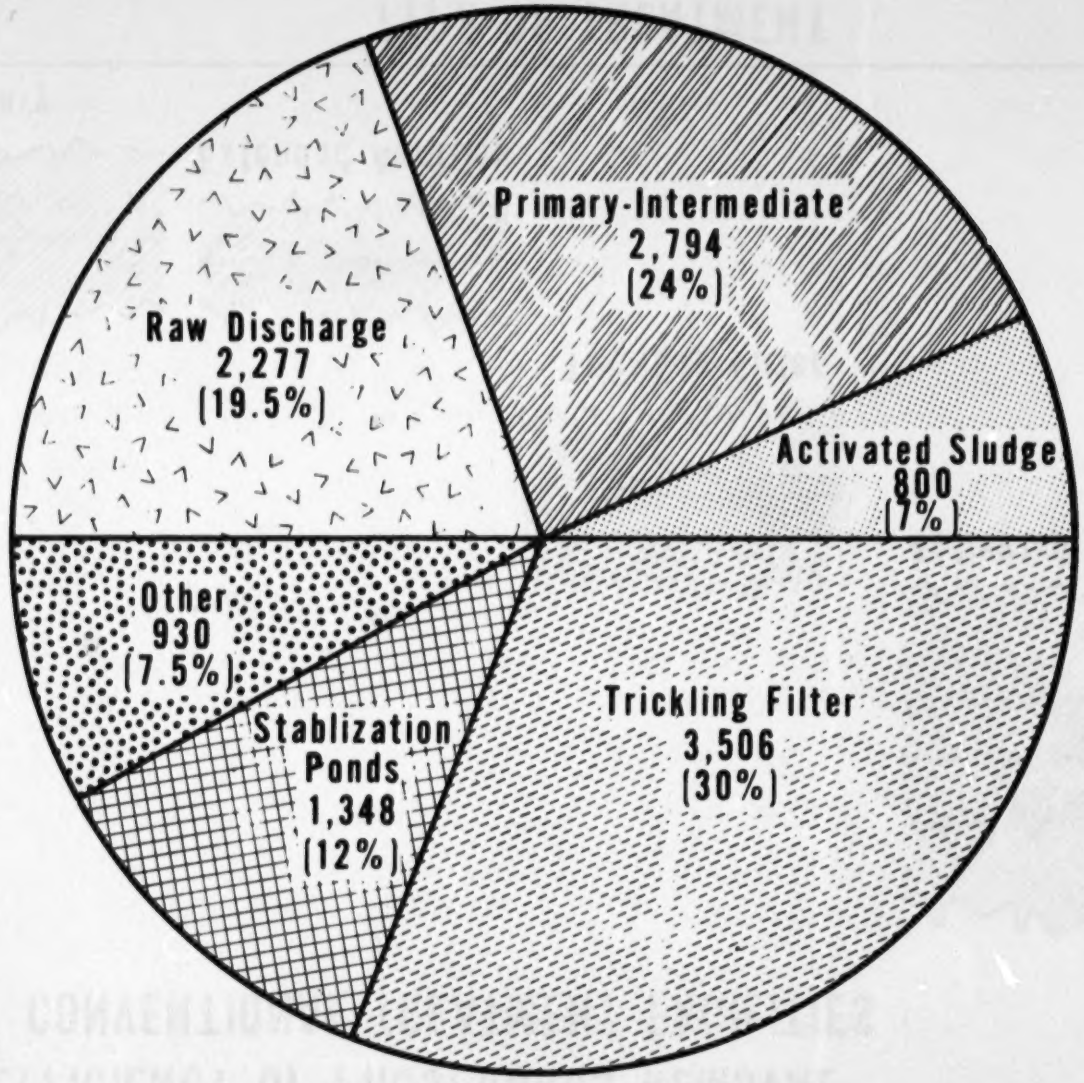
Attached are the group of tables and figures that will be used to present this subject.

POPULATION WITH WASTE SYSTEMS
PHS SURVEY 1962

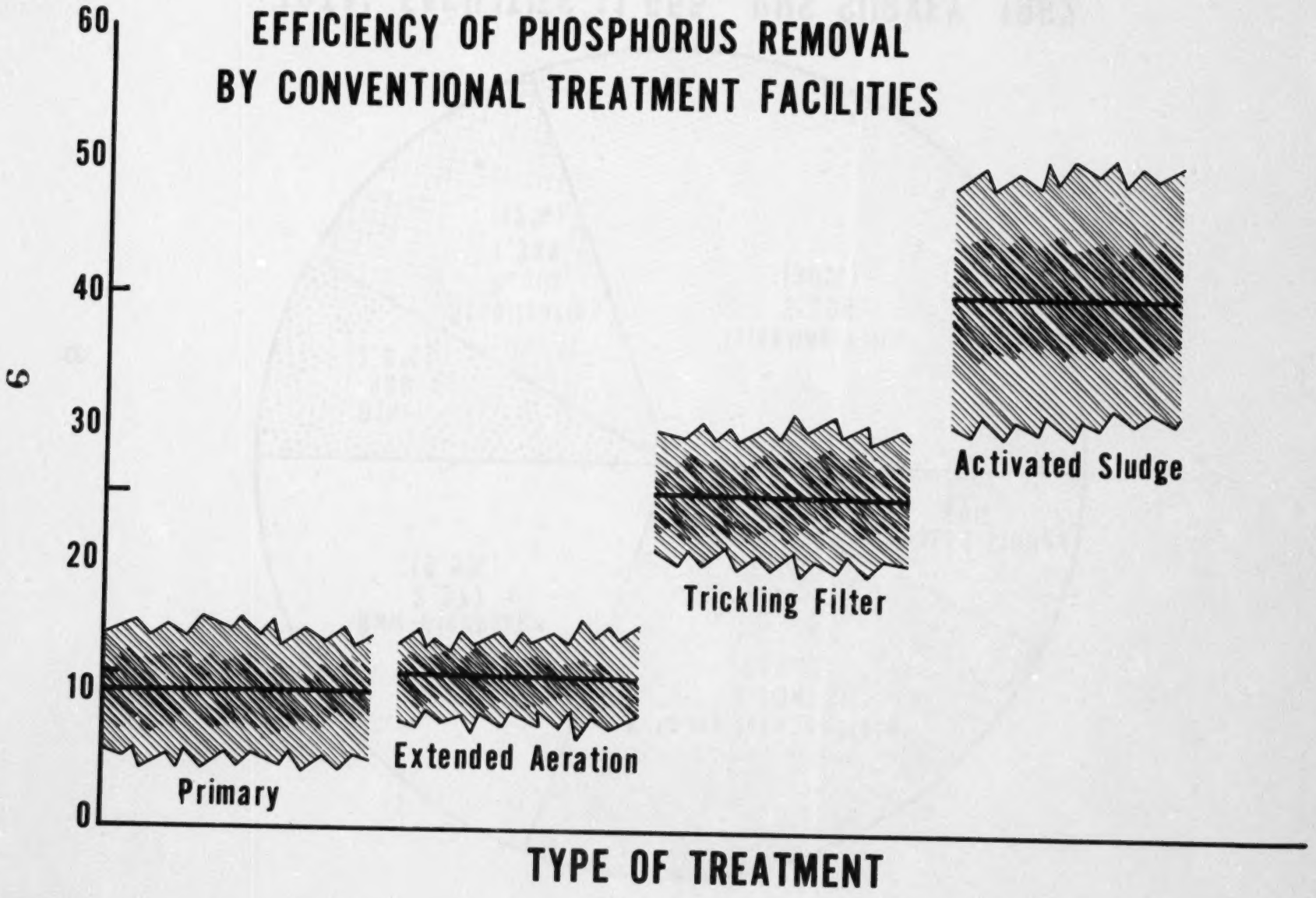


TREATMENT CLASSIFICATION BY POPULATION
PHS SURVEY 1962





TOTAL FACILITIES 11,655 PHS SURVEY, 1962


EFFICIENCY OF PHOSPHORUS REMOVAL
BY CONVENTIONAL TREATMENT FACILITIES
60
50
40
30
20
10
0
%
Primary
Extended Aeration
Trickling Filter
Activated Sludge
TYPE OF TREATMENT

ESTIMATE OF TOTAL AMOUNT OF PHOSPHORUS DISCHARGED TO WATER SYSTEM

Per capita contribution of phosphorus is 4 pounds per person per year

Population x per capita x efficiency	Pounds discharged
Not served by any treatment $70 \times 10^6 \times 4 \times 0.00$	280×10^6
Served by primary treatment only $40 \times 10^6 \times 4 \times 0.10$	154×10^6
Served by trickling filter or extended aeration $30 \times 10^6 \times 4 \times 0.25$	90×10^6
Served by activated sludge $40 \times 10^6 \times 4 \times 0.40$	96×10^6
Total pounds of phosphorus discharged to water system per year	610×10^6

PARAMETERS DEEMED NECESSARY FOR EFFICIENT BIOLOGICAL REMOVAL OF PHOSPHORUS

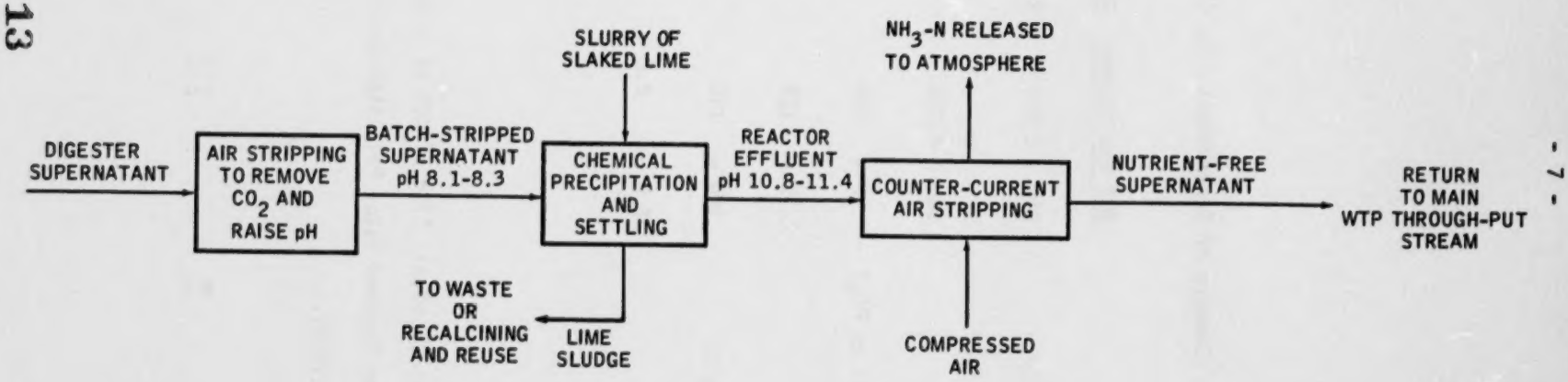
1. Eliminate Digester Supernatant Recycle
2. Aeration Time and Rate of Air Supply
3. Concentration of Mixed Liquor Suspended Solids
4. Concentration of Dissolved Oxygen in Aerator
5. Period of Sludge Retention in Secondary Clarifier
6. Additional Benefit Possible by Stripping of Phosphorus from Return Sludge
    a) Anaerobic Stripping
    b) Acid Stripping

Summary of Supernatant Data (6)

Analysis	80% Confidence	Median	Mean
Bicarbonate Alkalinity (mg/l as $CaCO_3$)	850 - 2,950	1,580	1681
5-Day BOD (mg/l)	500 - 4,260	910	1401
Total Phosphate (mg/l as PO_4)	46 - 380	132	211
(mg/l as P)	15 - 124	43	69
Ammonia Nitrogen (mg/l)	100 - 710	405	413
pH	6.6 - 8.0	7.3	7.3

(6) Masselli, Joseph W. et.al. "The Effect of Industrial Wastes on Sewage Treatment". New England Water Pollution Control Commission, Boston, Massachusetts (1965).

SUPERNATANT BENEFICIATION PILOT PLANT TREATMENT SEQUENCE

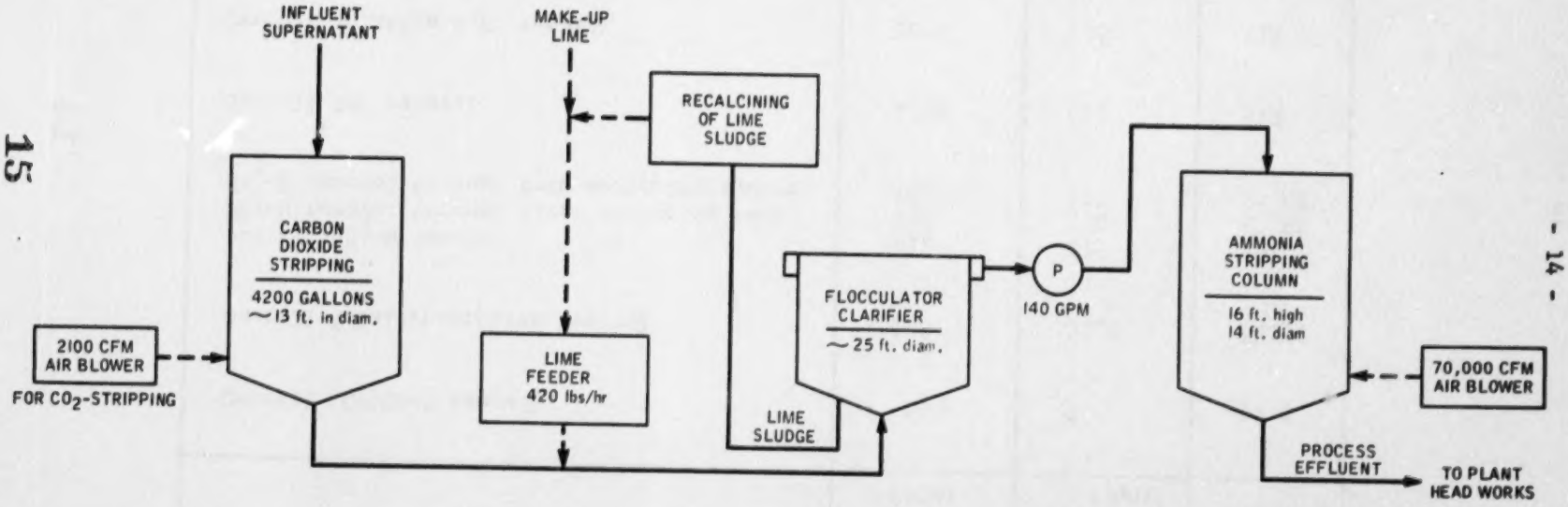


OVERALL PILOT PLANT PERFORMANCE
(RUN NOS. 1 – 13)

	AVERAGE INFLUENT (PPM)	AVERAGE EFFLUENT (PPM)	AVERAGE REMOVAL
Overall Ortho-P removal	65	5	92 %
Overall Total Phosphorus removal	138	22.5	84.5%
Overall NH_3-N removal	812	175	79%
NH_3-N removal through first stripping tower	763	330	57.5%
NH_3-N removal through both stripping towers	763	175	77.5%
Overall TOC removal	1202	590	51%
Overall Volatile S.S. removal	1679	426	71%
Overall Suspended Solids removal	2262	647	69%

March 1970

TYPICAL
SUPERNATANT BENEFICIATION
FACILITIES FOR 50 MGD PLANT*



*PRODUCING IRVINGTON-TYPE SUPERNATANT

CONTROL OF HYDRAULIC OVERLOAD

1. FIND AND REDUCE NEEDLESS SOURCES

2. CONSIDER USING LARGE INTERCEPTORS
   AS HOLDING TANKS

3. CONSTRUCT SURGE TANK
   FANCY
   PLAIN

4. ENLARGE PLANT

CONTROL OF ORGANIC OVERLOAD

1. SURGE TANK TO SMOOTH LOAD
2. HAVE INDUSTRY PROGRAM LOAD
3. POLYMERS DURING BULKING
4. PROGRAM DIGESTER SUPERNATANT RECYCLE OR ELIMINATE
5. INSTALL ROUGHING FILTER - IN LINE OR LOOP OPERATION
6. CONSIDER TWO-STAGE TREATMENT

IMPROVE FINAL SOLIDS SEPARATION

1. CONTROL RECYCLE
2. POLYMERS OR WEIGHTING AGENTS
3. LAGOON
4. COARSE – SAND FILTRATION
5. INCREASE SETTLER CAPACITY
6. ADVANCED PROCESSES

ADVANCED WASTE TREATMENT AND

WATER REUSE SYMPOSIUM

January 12-14, 1971

Dallas, Texas

COMBINED BIOLOGICAL-CHEMICAL TREATMENT FOR CONTROL OF PHOSPHORUS

Richard C. Brenner
Advanced Waste Treatment Research Laboratory
U.S. Department of the Interior
Federal Water Quality Administration
Ohio Basin Region
Cincinnati, Ohio

COMBINED BIOLOGICAL-CHEMICAL TREATMENT FOR CONTROL OF PHOSPHORUS

Richard C. Brenner

INTRODUCTION

The sanitary engineer has three basic options available today in designing waste treatment systems to remove phosphorus. As shown in Figure 1, the three options are straight biological removal, straight chemical precipitation, and combined biological-chemical removal.

Biological removal is dependent on manipulating aeration system operating parameters to maximize cell synthesis and so-called luxury phosphorus uptake. Overall removal efficiency is improved by breaking the digester recycle and treating supernatant separately. To date, however, luxury phosphorus uptake has not proven to be a predictable phenomenon which can be effectively applied to activated sludge plants across the board. For reliable phosphorus removal, one of the other two options should be selected.

The major difference in straight chemical precipitation and combined biological-chemical removal is the point of chemical addition. Strict chemical precipitation schemes add the chemicals either prior to the biological unit in the primary settler or after the biological unit in a tertiary step using biological effluent as feed. Other examples of straight chemical applications are the new physical-chemical plants which do not include a biological phase. Combined biological-chemical removal utilizes direct dosing of mineral salts to the biological unit itself.

PHOSPHROUS PRECIPITANTS

The available chemicals which we know today will effectively precipitate phosphorus from solution are listed in Figure 2. They include aluminum and iron salts and lime. Precipitation with metal salts is based on the low solubility of metallic phosphorus compounds at typical wastewater pH ranges. The required dose of the metal ion is stoichiometrially related to the incoming phosphorus concentration. Precipitation with lime is independent of phosphorus concentration; it is dependent on pH and bicarbonate alkalinity. The rationale for lime precipitation is the very low solubility of hydroxyapatite at elevated pH.

All of the above chemicals are applicable to strict chemical precipitation systems. Only the metallic salts, however, are effective and economically realistic when dosed directly to a biological treatment unit. Excessive doses of lime are needed to overcome the natural buffering action of biological systems.

When metallic salts are added to the primary settler to remove phosphorus, small doses of anionic polymers are also recommended to improve flocculation and settleability. If the polymer is not added, much of the insolubilized phosphorus particles may carry over into the next step of the treatment sequence. It may further be necessary in certain instances to supply additional alkalinity in the form of lime or caustic soda to the primary settler to achieve effective flocculation and solids capture. This is particularly true with ferrous chemicals.

The presence of naturally occurring polymeric materials in activated sludge eliminate the necessity of commercial polymer aids in combined biological-chemical applications. The biological floc serves as the coagulant mechanism to capture precipitated phosphorus particles.

BASIC PRINCIPLES OF COMBINED BIOLOGICAL-CHEMICAL REMOVAL (MINERAL ADDITION)

The practice of adding chemicals to activated sludge plants to remove phosphorus will be referred to hereinafter as mineral addition. Precipitation of phosphorus takes place in the aeration tank. The metallic-rich sludge which is formed is continuously separated in the secondary settler and recycled to the head of the aerator. Adsorption and flocculation of phosphate precipitates is enhanced by the presence of the combined biological-chemical sludge and biologically generated polymeric materials. Precipitated phosphorus is removed from the process in the waste activated sludge. The waste sludge from a mineral addition process can be thickened and disposed of with the same techniques used for conventional biological sludges. Excepting that which is incorporated in cells to satisfy metabolic needs, the phosphorus removed in the sludge is chemically bound and is not released during aerobic or anaerobic digestion.

Figure 3 indicates alternative dosing points for mineral addition. The minerals can be added with relatively equal phosphorus removal expectancy to the primary effluent, a flash mix tank just prior to final sedimentation, the recycle sludge, or at any point in the aeration tank. Individual plant configurations and a few trial and error runs will usually dictate the most preferred dosing point for a particular situation.

ADVANTAGES OF MINERAL ADDITION

The mineral addition technique possesses several inherent advantages for activated sludge plants. These advantages are summarized in Figure 4 and include minimum capital expenditure, reduced chemical requirement, improved mixed liquor settling and the resultant capability of carrying higher mixed liquor volatile suspended solids loadings in the aerator, and a large reduction in phosphorus recycle back to the main flow stream via digester supernatant.

Capital expenditures are limited to chemical feed equipment, storage facilities, and dosing control instrumentation. Mixing is accomplished in the aeration tank and phosphorus precipitates are removed in the existing settler.

Reduced chemical requirements can be traced to biological-chemical interaction and the large floc surface area available for adsorption. As shown in Figure 5, the alum requirement for equivalent phosphorus removal using the mineral addition approach is only about 75% of that for a strictly tertiary application.

In comparing mineral requirements for dosing to the aerator versus dosing to the primary, there is the further consideration of the form of the phosphorus. Inorganic phosphorus in raw sewage is normally divided about equally between polyphosphate and orthophosphate. Polyphosphate is rapidly hydrolyzed to orthophosphate by the enzymatic action of activated sludge. Precipitation of phosphorus is much more efficient in the ortho form than in the poly form. Thus, less mineral supplement is needed in the aerator than for an equivalent removal in the primary.

Figure 6 shows the results of a pilot plant experiment conducted several years ago at the Advanced Waste Treatment Research Laboratory (AWTRL) in Cincinnati (1). Sodium aluminate was added to the pilot plant after an initial base run period. The improvement in sludge density index effected by mineral addition is readily apparent. This made possible an approximate two-fold increase in the concentration of mixed liquor volatile suspended solids, thereby nearly halving the organic loading to the system. In general, the greater the bulking tendency of a sludge, the more marked will be the improvement in settling characteristics with mineral addition.

The ultimate fate of phosphorus with mineral addition is also evident in Figure 6 (1). The phosphorus concentration in digested sludge in the above experiments rose by 235% after aluminum addition while the concentration in the supernatant fell to a third of its former level. Phosphorus precipitated by the aluminum ion was not released during anaerobic digestion. That which did remain in the supernatant was solubilized during digestion from the primary sludge which received no chemical dosing and from non-chemically bound phosphorus used to satisfy cell matabolic needs.

LIMITATIONS OF MINERAL ADDITION

It is important to understand the limitations of a process to use it properly. The mineral addition process for activated slusge plants is highly efficient in removing the bulk of phosphorus from wastewaters.

Effluent concentrations of 1-2 mg/l as P are readily achievable. The difference between 1 and 2 mg/l is largely a function of suspended solids removal. If final clarification is followed by sand filtration, effluent phosphorus can be further lowered to 0.5-1.0 mg/l as P. It is difficult to obtain residual phosphorus levels below 0.5 mg/l with mineral addition due to the solubility products of aluminum and iron phosphates. If residual phosphorus levels below 0.5 mg/l are mandatory, tertiary lime precipitation is recommended.

COMPARISON OF ALUMINUM AND IRON PRECIPITANTS

Two aluminum compounds have proved satisfactory for mineral addition. They are sodium aluminate and aluminum sulfate (alum). Four iron compounds have been used by various researchers including ferric chloride, ferrous chloride, ferric sulfate, and ferrous sulfate.

Three inherent factors favor use of the aluminum products over the iron products. First, iron forms colored compounds; aluminum compounds are white. Effluent discoloration is a greater possibility with iron than with aluminum. Second, iron undergoes oxidation-reduction reactions; aluminum does not. Therefore, the possibility does exist that iron phosphate sludge could be reduced during digestion and the phosphorus subsequently resolubilized. Reduction is not possible with aluminum. Third, all of the iron compounds are highly acidic, whereas both acidic and basic forms are available with aluminum. Aluminum thus offers a choice in selecting the proper chemical to match wastewater alkalinity.

Favoring iron is the fact that commercial grade iron compounds are slightly cheaper than commercial grade aluminum compounds for equivalent phosphorus removal. Also, iron compounds are more frequently available as impure waste streams, e.g. pickle liquor. These impure waste streams can usually be purchased for the cost of trucking alone, thereby significantly lowering the cost of phosphorus removal.

COMPARISON OF ALUM AND SODIUM ALUMINATE

The caracteristics of the two aluminum salts are summarized in Figure 7. Alum is highly acidic, uses up alkalinity reserve, and lowers pH. Sodium aluminate is highly basic, acts as a natural buffer, and causes pH to elevate slightly.

Both compounds are available in liquid and powder form. The alum forms contain a higher percentage of water than their aluminate counterparts. Alum is produced in more than fifty locations around the country. There are only three major aluminate production centers. Delivery of liquid alum is limited to approximately 100-125 miles. At distances greater than this, powdered alum becomes more economical.

Both liquid alum and aluminate are more easily handled and metered into a treatment process than the powder forms. No dissolving equipment is required for the liquids. However, temperature is a factor to consider in both transport and storage of the liquid forms. Liquid alum crystallizes at 4°F; liquid aluminate at -20°F. Both materials, particularly liquid aluminate, become increasingly viscous as temperature drops. Indoor storage is preferred. Insulated tanks and steam tracing will be necessary in colder climates for outdoor storage.

SIDE EFFECTS OF MINERAL ADDITION

Regardless of the precipitant used, some extraneous and unusuable ion is added to the water. These extraneous ions are a form of pollution themselves. In the cases of alum, ferric sulfate, and ferrous sulfate, sulfate is the extraneous ion which remains in solution. For ferric and ferrous chloride, the extraneous ion is chloride. Sodium is the extraneous ion for sodium aluminate. The quantities of extraneous ion added per pound of metal ion are shown in Figure 8. The increase in total dissolved solids for equivalent phosphorus removal using aluminate is six times less than for alum and 3-6 times less than for the various iron compounds.

MATCHING OF PROPER CHEMICAL TO WASTEWATER ALKALINITY

Two examples will be utilized below to illustrate the importance of considering wastewater alkalinity before selecting the mineral additive.

The first example is taken from data collected during experiments at the AWTRL in Cincinnati in which alum and aluminate were dosed separately to two parallel and identical activated sludge pilot plants (2). Doses to the two plants as mg/l of aluminum ion were equivalent. The same wastewater with a moderate alkalinity varying from 100-200 mg/l as $CaCO_3$ served as the feed to both plants. As seen in the sequence of Figures 9 through 12, the performance of the alum fed unit was much more erratic than that of the aluminate fed unit. This can be traced to the nearly constant decrease in alkalinity of 100 mg/l as $CaCO_3$ exhibited in the alum fed unit. When the alkalinity of the primary effluent entering the alum fed aerator was down near 100 mg/l, the alum caused the alkalinity to approach zero with a concurrent substantial drop in pH (day 16). The microbial population, not being acclimated to the lower pH, suffered through a several day recovery period during which effluent turbidity and phosphorus rose significantly. Alkalinity and pH of the aluminate fed unit were relatively unaffected and performance was consistent throughout the study. Overall performance of the two parallel pilot units for various treatment parameters is summarized in Figure 13. In this case, aluminate is clearly the preferred additive.

In a contrasting study at the joint FWQA-Los Angeles County Sanitary District pilot plant in Pomona, California, the opposite situation was observed (3). The wastewater at this site has a fairly high alkalinity of 300-400 mg/l as $CaCO_3$. At typical phosphorus concentrations, the required alum dose is far short of that which would reduce alkalinity to low levels. Aluminate, however, being basic, tends to increase hydroxide alkalinity and pH. Comparative unfiltered effluent phosphorus values in Figure 14 indicate superior performance with alum at equivalent aluminum ion doses. In this instance, alum, or any of the iron compounds which are also acidic, is a better choice than aluminate.

From these two examples, it can be postulated that aluminate is better suited to wastewaters with low to moderately low alkalinity while alum and iron compounds are better suited to wastewaters with moderately high to high alkalinity.

REQUIRED MINERAL DOSES

In the same Cincinnati study (2) mentioned previously in which alum and aluminate were compared, % total phosphorus removed across the secondary was plotted against the dosing ratio of aluminum ion to phosphorus (Al/P). Discarding the data from the alum fed unit on those days when the unit was upset, alum and aluminate exhibited equal capability to remove phosphorus.

The following information can be extracted from the curve plotted in Figure 15. At an Al/P dose of 1/1, by weight (mole ratio of 1.15/1), 80% phosphorus removal can be expected. Removal expectancy is increased to 90% at an Al/P dose of 1.2/1, by weight (mole ratio of 1.4/1). Above 1.2/1, there is a diminishing return in incremental phosphorus removed. Maximum removal of 93% total phosphorus was achieved at Al/P doses of 1.4/1 to 1.5/1, by weight. Increasing the dose further only succeeded in decreasing overall removal. One hypothesis for this phenomenon is that stable aluminum phosphate colloids were formed with the excessive Al doses that resisted settling.

Assuming equivalent phosphorus removal at mole ratios of 1.15/1 and 1.4/1, the required Fe/P doses to achieve 80% and 90% removal are 2.1/1 and 2.5/1, by weight, respectively.

FIELD STUDIES AT ACTIVATED SLUDGE PLANTS

Two full scale field studies can serve to demonstrate the applicability of the mineral addition process to actual activated sludge plants.

The first was conducted by AWTRL staff personnel at the 1 mgd Xenia, Ohio Little Miami Plant in the summer of 1967 (4). In this six-week study, sodium aluminate was added directly to the head of the aerator.

Figure 16 shows that phosphorus removal approached 90% at Al/P doses of 1.5/1 to 1.8/1 by weight. The temporary dosing system utilized did not always properly match Al to P with the result that overall phosphorus removal suffered slightly. Improvement in activated sludge settling and concentration was noted throughout.

The second study was conducted in 1969 under an FWQA research grant to the University of Texas, Medical Branch, on Texas City, Texas Plant No. 2 (5). Waste pickle liquor ($FeSO_4$) was dosed directly to raw sewage before primary sedimentation. Since no polymer was added, the primary settler showed negligible phosphorus removal. Insolubilized phosphorus particles carried through to the aeration tank where overall removal was excellent. As indicated in Figure 17, an effluent phosphorus level of approximately 1 mg/l as P was reliably achieved at an Fe/P mole ratio of 1.4/1 to 1.5/1. Upon cessation of ferrous addition on June 13 (Figure 18), effluent phosphorus increased dramatically to a background level of 9-10 mg/l as P. Equally effective results were obtained throughout the dosing program even though mixed liquor suspended solids concentrations varied from 2000-4200 mg/l. The Texas City study demonstrated that insolubilized phosphorus has little affinity for settling in the primary without polymer. When primary sedimentation is followed with activated sludge treatment, dosing of the mineral to raw sewage or primary effluent appears to make little difference in overall phosphorus removal efficiency.

DIRECT DOSING OF A TRICKLING FILTER

To ascertain the applicability of mineral addition to trickling filters, one of three Fairborn, Ohio trickling filters was dosed directly with sodium aluminate for a four-week period in the summer of 1968 (6). Total flow to the plant of 3 mgd was split equally between the three filters. One of the undosed filters was used as a control. The results are given in Figure 19. Overall phosphorus removal with the dosed filter averaged 64% compared to 17% for the control filter. Performance was otherwise unaffected.

It can be concluded that direct mineral dosing is considerably less effective for a trickling filter than for activated sludge. The apparent reasons are insufficient mixing, reduced residence time, and the absence of freely moving biological flocculators. Straight chemical precipitation in either the primary or final clarifiers is recommended for trickling filters in preference to direct dosing across the filter media.

EXCESS SLUDGE PRODUCTION WITH MINERAL ADDITION

Excepting any improvement effected in secondary clarification, the additional sludge produced via mineral addition can be attributed to the precipitation of mineral-phosphate complexes. The quantity of excess sludge so generated is a legitimate concern of treatment plant designers.

Two recently conducted studies provide information on this subject. The first was conducted at the joint FWQA-Prince William County, Virginia pilot plant in Manassas, Virginia using only aluminum salts (7). Excess sludge production was found to be a straight line function up to the stoichiometric requirement of aluminum ion. Stoichiometric requirement is defined as that amount of aluminum ion which yields a 1/1 mole ratio of Al/P. Above the stoichiometric dose, excess sludge production tailed off sharply. Figure 20 shows that at Manassas 4 mg/l of excess sludge were produced for every mg/l of aluminum ion added up to the stoichiometric dose of 13.5 mg/l of Al. However, it was also found that improvement in sludge volume index and sludge dewaterability due to the aluminum compensated for increased sludge mass to the extent that net volume of waste sludge remained the same and dewatering capacity did not have to be enlarged.

Both aluminum and iron salts were fed to a small package plant in New Berlin, Wisconsin during a programmed study in 1968 (8). Additional solids production ranged from 7-8 pounds per pound of phosphorus removed throughout although one would intuitively expect more excess sludge with iron due to its higher atomic weight. The increase in the total weight of solids wasted was approximately 100%. However, as at Manassas, a considerable improvement in mixed liquor settling rate, settled volume, and drainability was noted. Volumetric waste sludge requirements were increased by only 35%.

COST CONSIDERATIONS FOR MINERAL ADDITION

Under present pricing structures, alum is less costly than aluminate. Figure 21 indicates that for equivalent aluminum ion content, powdered alum is about 15% cheaper than powdered aluminate and that liquid alum is approximately 35% cheaper than liquid aluminate. The prices shown here are bulk delivered prices to the Greater Cincinnati area from the nearest production site for each chemical.

The alum pricing structure is very stable owing to an extensive existing market in the water treatment and paper industries. On the other hand, aluminate pricing is much more elastic and the opening of a major new market in wastewater treatment could quite conceivably lower the bulk purchase rate significantly. Widespread utilization of the mineral addition technique for phosphorus removal would almost certainly diminish the current price differential in the two compounds.

Reduced to a unit cost basis, the chemical cost for 80-90% phosphorus removal using aluminum salts will range from about $25-45 per million gallons treated for an influent phosphorus concentration of 10 mg/l as P.

Figure 22 lists the various options for the two levels of desired removal. Liquid alum is the least expensive; liquid aluminate is the most expensive. An alum + lime option is included for those plants which have low alkaline wastewater but may choose to use lime doses to the aerator to replenish alkalinity depleted by the alum rather than switch to the basic but more costly aluminate. As shown in Figure 23, ignoring the increased total dissolved solids added thereby, alum + lime is still somewhat cheaper than aluminate alone using the cheapest present day source of both aluminum products.

Chemical costs for iron compounds varies considerably with the location and the availability of waste pickle liquor. Commercial grade iron compounds will cost approximately the same or slightly less than alum for equivalent phosphorus removal. Waste pickle liquor, though, if available, will bring the chemical cost down to a fraction of the cost using high grade precipitants. The University of Texas research grant project is a good example (5). The Texas City, Texas Plant No. 2 utilized for the study has a normal phosphorus load of about 10 mg/l as P. To obtain 90% phosphorus removals, a mole ratio of Fe/P of 1.5/1 was required. Using commercial grade ferrous sulfate ($FeSO_4 \cdot 7H_2O$) at $0.095 per pound of available Fe, the chemical cost would have been $20 per million gallons treated (2 ¢ per thousand gallons). However, waste ferrous sulfate pickle liquor (30-45% $FeSO_4 \cdot 7H_2O$) was made available to the project at a cost of $0.015 per pound of available Fe. The resulting chemical cost was $3.2 per million gallons treated (0.32 ¢ per thousand gallons), or about 1/6 the cost with commercial grade ferrous sulfate.

A relatively modest investment will purchase the necessary capital equipment for mineral addition. The requirements are storage tanks, feed pumps and plumbing, and for accurate chemical proportioning to incoming phosphorus a controlled dosing system. One variation of a controlled dosing system is shown in Figure 24. Hydraulic flow and incoming phosphate are continuously monitored. A positive displacement controlled volume pump is utilized to meter in the liquid chemical. The drive speed of the pump is automatically controlled as a coarse adjustment by an electrical signal from the flow recorder. A signal from the continuous phosphate analyzer is used to automatically vary piston stroke length as the fine adjustment. In this manner, the ratio of chemical fed to influent phosphorus is always maintained at a predetermined level. The system described above is a dual automatic open loop system. The critical piece of hardware is the continuous on-line phosphate analyzer. Individual investigators have modified laboratory analyzers to serve in an on-line capacity but, to date, no company is marketing an on-line model.

The total cost of phosphorus removal via mineral addition including chemicals, O & M, and debt retirement is estimated in Figure 25. In this

example, liquid alum is costed in at the dose required to remove 90% of a phosphorus load of 10 mg/l as P. It is readily apparent that chemicals constitute the major cost element, particularly for larger plants. Incremental costs for phosphorus removal over and above the total annual operating costs for normal operation of an activated sludge plant are estimated at roughly 25-45%, depending on plant size. Clearly, if we are going to consider phosphorus a major pollutant of the same magnitude as organic carbon and suspended solids, we have to be willing to pay a price for its removal which approaches the unit cost of either organic carbon or suspended solids removal.

FWQA GRANT AND CONTRACT PROJECTS USING MINERAL ADDITION

Itemized below is a list of current FWQA projects using mineral addition to activated sludge systems to remove phosphorus. Several of the projects are in the design or construction phase and are not yet generating data.

1. Penn State University - 2 mgd (alum)
2. University of Texas (Texas City) - 0.75 mgd (waste pickle liquor)
3. University of Notre Dame - 50,000 gpd (aluminate)
4. Manassas, Virginia - 1 mgd (aluminate)
5. New York State Environmental Conservation Department (West Coxsackie, N. Y.) - 0.1 mgd (aluminate)
6. Detroit, Michigan - 7,000 gpd (waste pickle liquor)
7. Xenia, Ohio (Little Miami) - 1 mgd (aluminate)
8. Seattle, Washington (METRO) - 20 mgd (aluminum salts)
9. New York City - 20 mgd (alum)
10. Milwaukee, Wisconsin - 80 mgd (iron salts)

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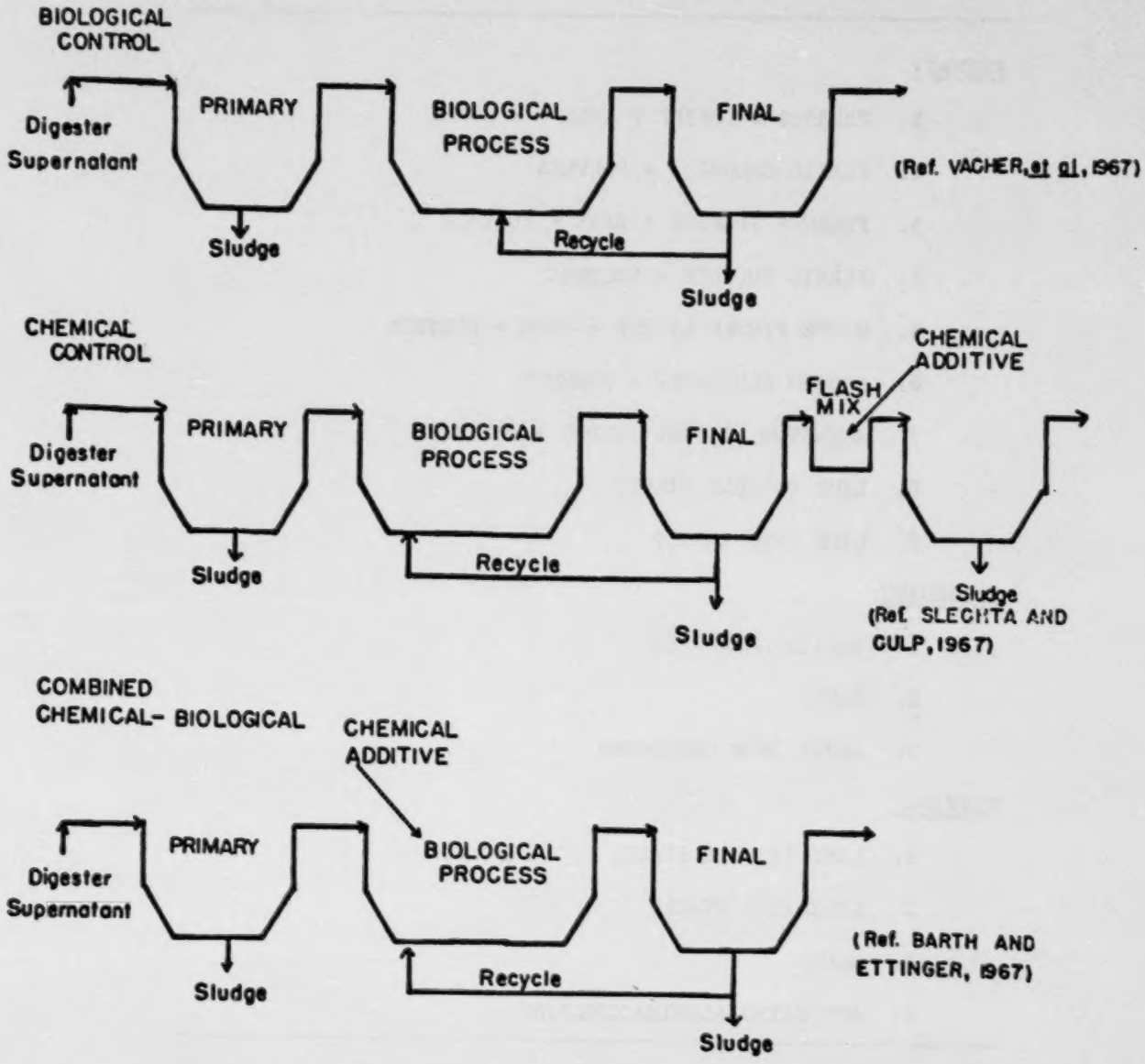


FIGURE I. PHOSPHORUS CONTROL BASIC SYSTEMS

FIGURE 2

CHOICE OF CHEMICALS FOR PHOSPHORUS REMOVAL

PRIMARY

1. FERROUS CHLORIDE + BASE + POLYMER
2. FERRIC CHLORIDE + POLYMER
3. FERROUS SULFATE + BASE + POLYMER
4. FERRIC SULFATE + POLYMER
5. WASTE PICKLE LIQUOR + BASE + POLYMER
6. SODIUM ALUMINATE + POLYMER
7. ALUMINUM SULFATE (ALUM) + POLYMER
8. LIME (SINGLE STAGE)
9. LIME (TWO STAGE)

SECONDARY

1. SODIUM ALUMINATE
2. ALUM
3. ABOVE IRON COMPOUNDS

TERTIARY

1. LIME (SINGLE STAGE)
2. LIME (TWO STAGE)
3. ALUM
4. ACTIVATED ALUMINA COLUMNS

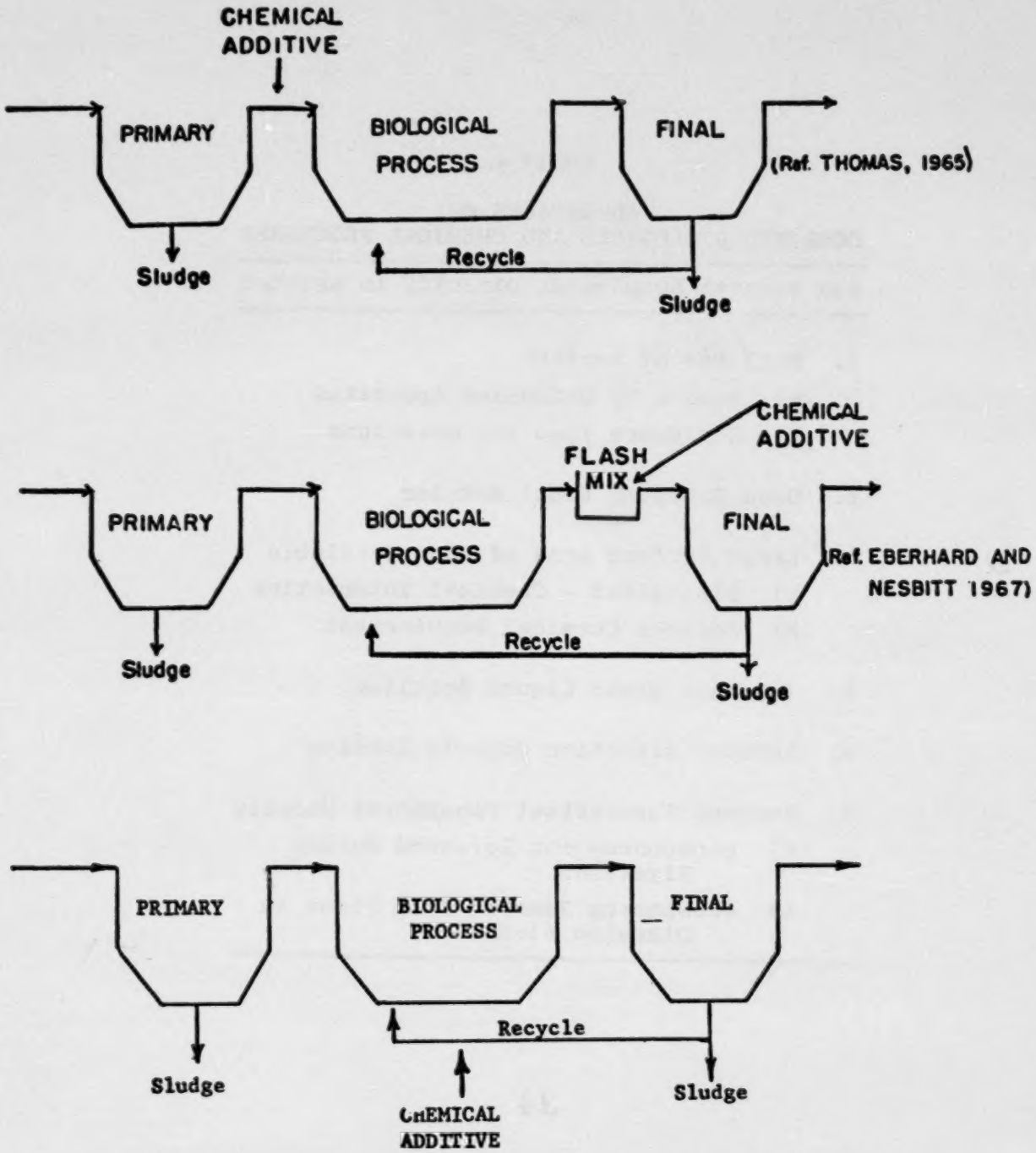


FIGURE 3. COMBINED CHEMICAL- BIOLOGICAL, VARIATIONS OF BASIC SYSTEMS

FIGURE 4.

ADVANTAGES OF
COMBINED BIOLOGICAL AND CHEMICAL PROCESSES

Add Mineral Supplement Directly to Aerator

1. Dual Use of Aerator
   a) Mixing by Diffusion Apparatus
   b) Residence Time for Reactions
2. Uses Existing Final Settler
3. Large Surface Area of Floc Available
   a) Biological - Chemical Interaction
   b) Reduces Chemical Requirement
4. Improves Mixed Liquor Settling
5. Reduces Effective Organic Loading
6. Reduces Supernatant Phosphorus Recycle
   a) Phosphorus not Released during Digestion
   b) Phosphorus Removed from Plant in Digested Sludge

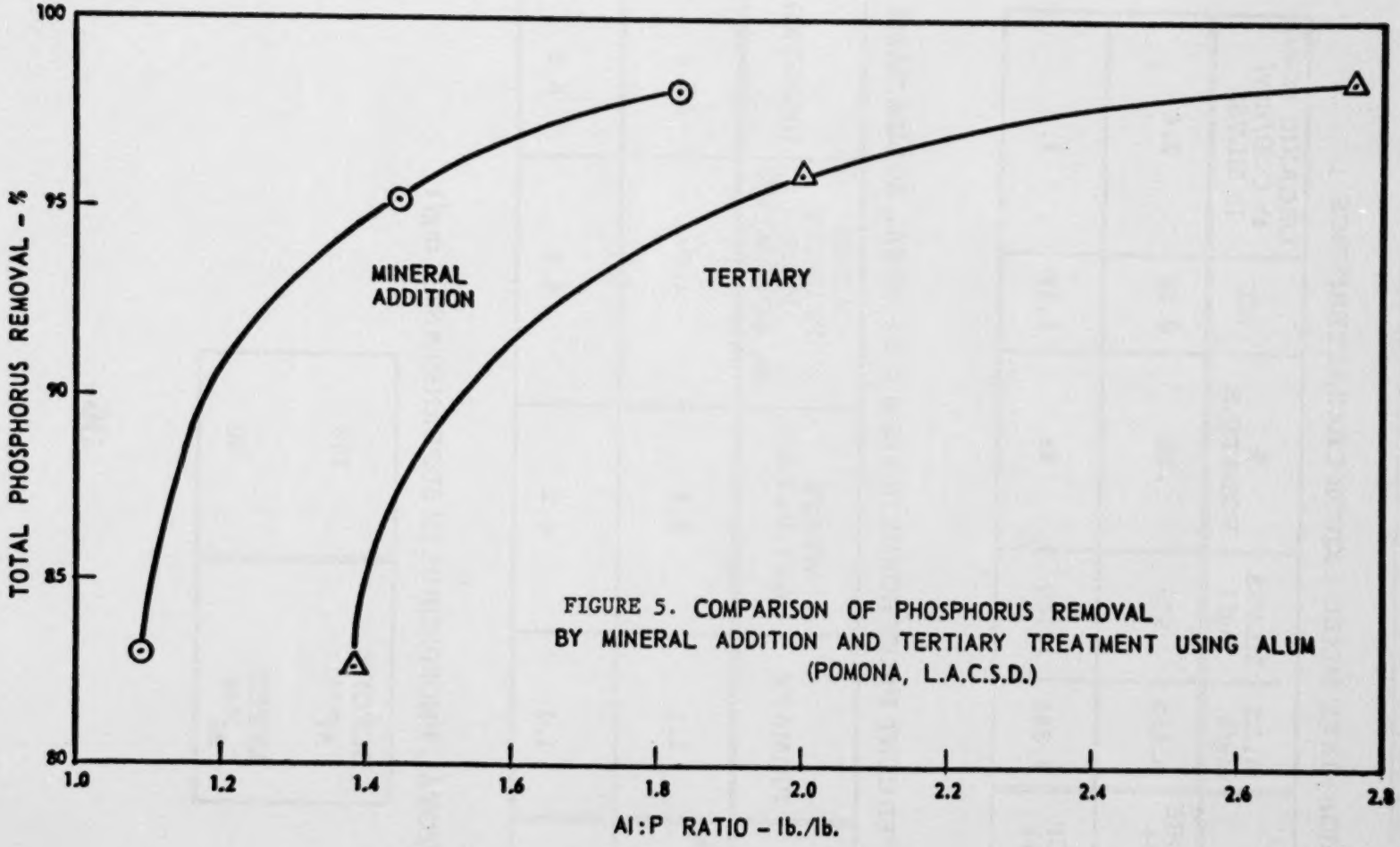


FIGURE 5. COMPARISON OF PHOSPHORUS REMOVAL BY MINERAL ADDITION AND TERTIARY TREATMENT USING ALUM (POMONA, L.A.C.S.D.)

FIGURE 6.

EFFECT OF ALUMINUM ON SLUDGES AND SUPERNATANT

1. HIGH-RATE MIXED LIQUOR CHARACTERISTICS

	MLSS mg/l	MLVSS mg/l	% VOLATILE	SDI	ORGANIC LOAD lb COD/day/ lb MLVSS
BEFORE Al^{+++}	1,450	900	62	0.44	2.6
AFTER Al^{+++}	3,385	1,740	51	1.12	1.6

2. PERCENT PHOSPHORUS IN SLUDGES - TOTAL SOLIDS BASIS

	PRIMARY	WASTE ACTIVATED	MIXED PRIMARY PLUS W. ACTIVATED	DIGESTED
BEFORE Al^{+++}	1.1	2.1	1.6	2.2
AFTER Al^{+++}	1.1	6.2	4.5	5.2

3. TOTAL PHOSPHORUS IN SUPERNATANT - mg/l

BEFORE Al^{+++}	170
AFTER Al^{+++}	60

FIGURE 7.

CHARACTERISTICS OF ALUMINUM SALTS

	(ALUM) ALUMINUM SULFATE		SODIUM ALUMINATE	
CHEMICAL FORMULA	$Al_2(SO_4)_3$		$Na_2Al_2O_4$ ($NaAl(OH)_4$ DISSOLVED)	
pH of 1% SOLUTION OF DRY CHEMICAL	3.5		11.9	
	DRY FORM	LIQUID FORM	DRY FORM	LIQUID FORM
% STATED CHEMICAL WT. BASIS	57	28	74	46
% Al - WT. BASIS	9.0	4.4	24.4	15.1

FIGURE 8.

SIDE EFFECTS OF MINERAL ADDITION

COMPOUND	EXTRANEOUS ION ADDED	LB EXTRANEOUS ION ADDED PER LB METAL ION *
ALUM	SO_4^{--}	5.35
SODIUM ALUMINATE	Na^+	0.85
FERROUS CHLORIDE	Cl^-	1.26
FERRIC CHLORIDE	Cl^-	1.91
FERROUS SULFATE	SO_4^{--}	1.72
FERRIC SULFATE	SO_4^{--}	2.58

*1 lb of Al ion is equivalent to 2.07 lb of Fe ion for precipitation of phosphorus.

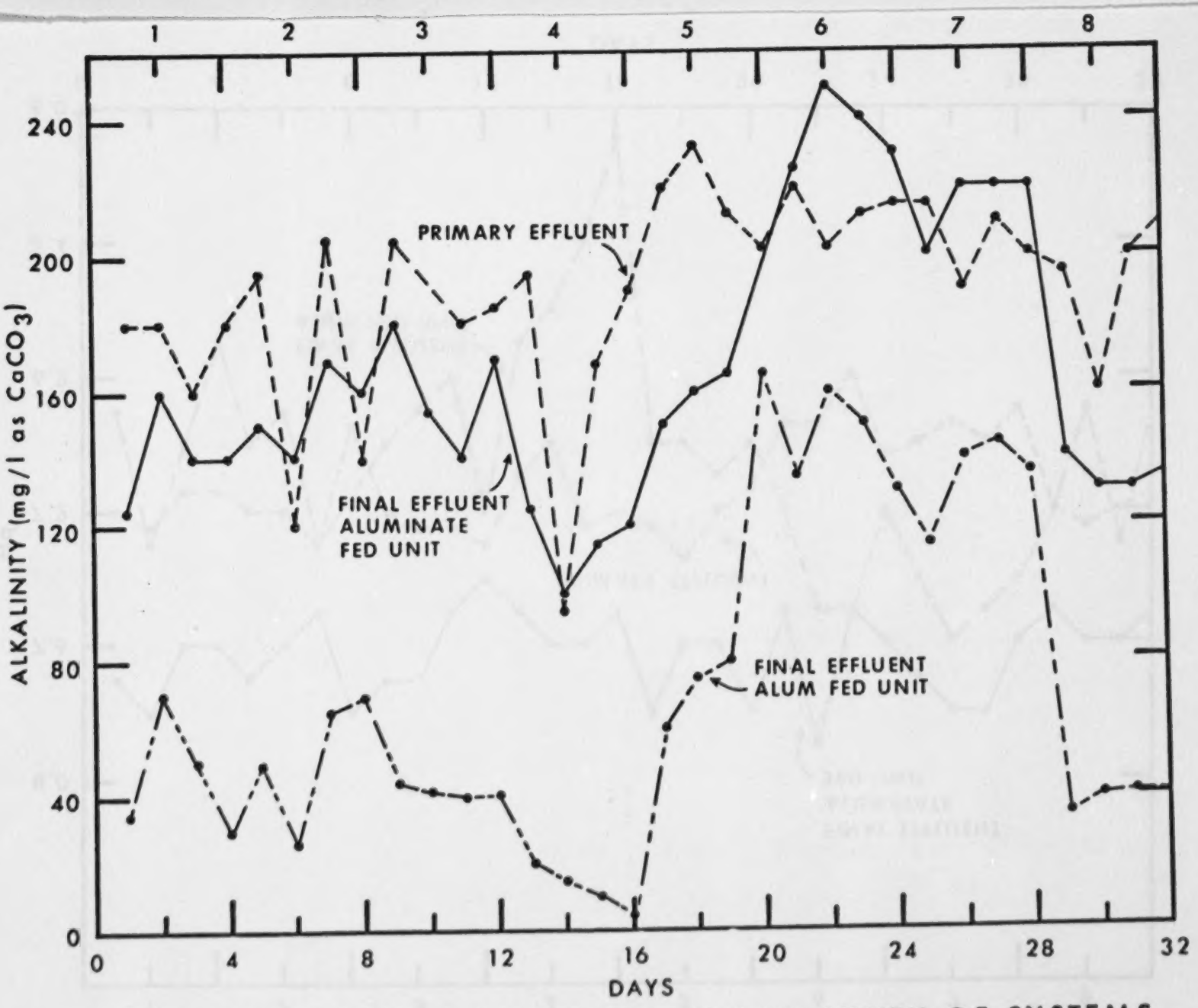
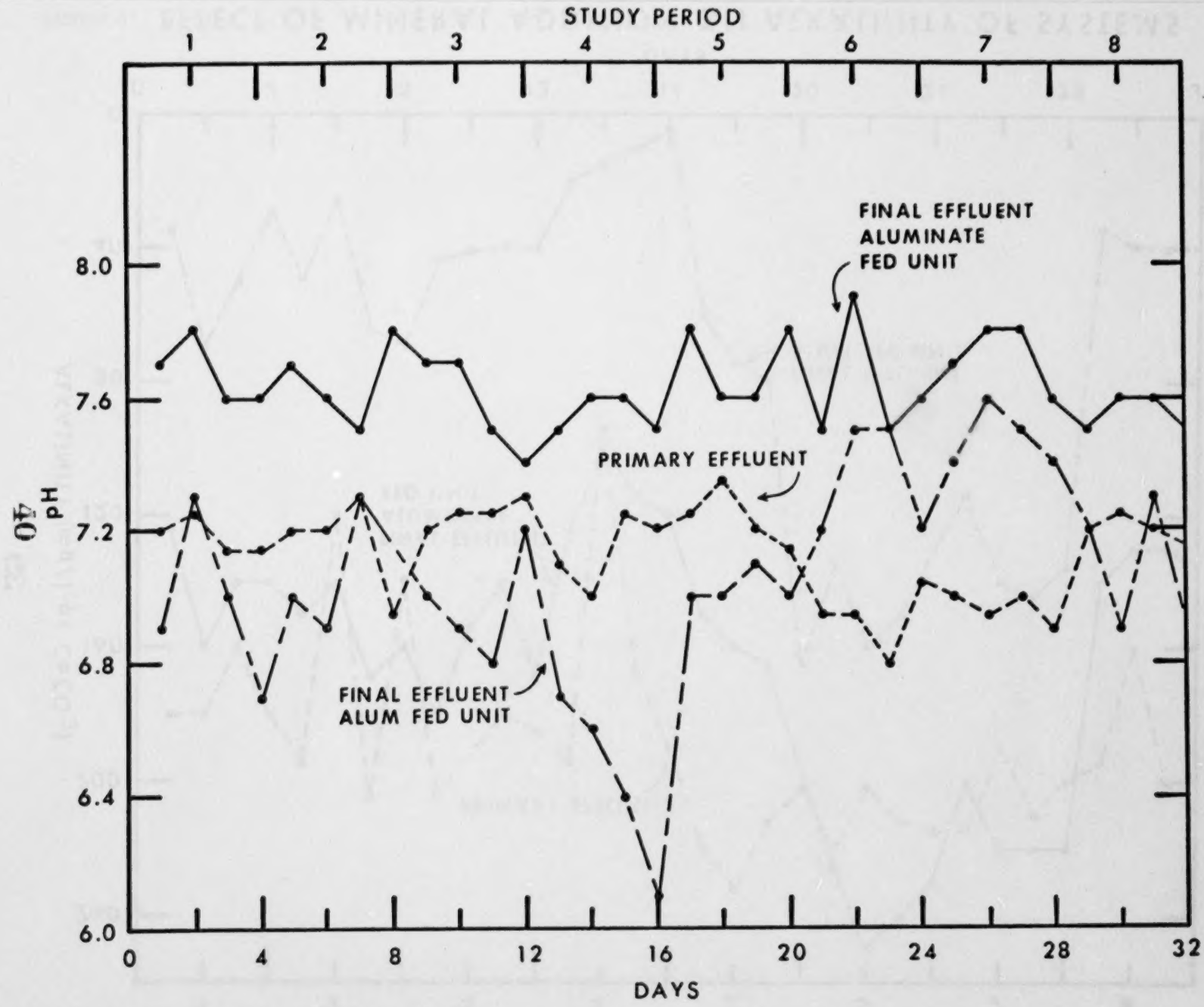


FIGURE 9. EFFECT OF MINERAL ADDITION ON ALKALINITY OF SYSTEMS


STUDY PERIOD
1
2
3
4
5
6
7
8
FINAL EFFLUENT
ALUMINATE
FED UNIT
PRIMARY EFFLUENT
FINAL EFFLUENT
ALUM FED UNIT
8.0
7.6
7.2
6.8
6.4
6.0
pH
0
4
8
12
16
20
24
28
32
DAYS

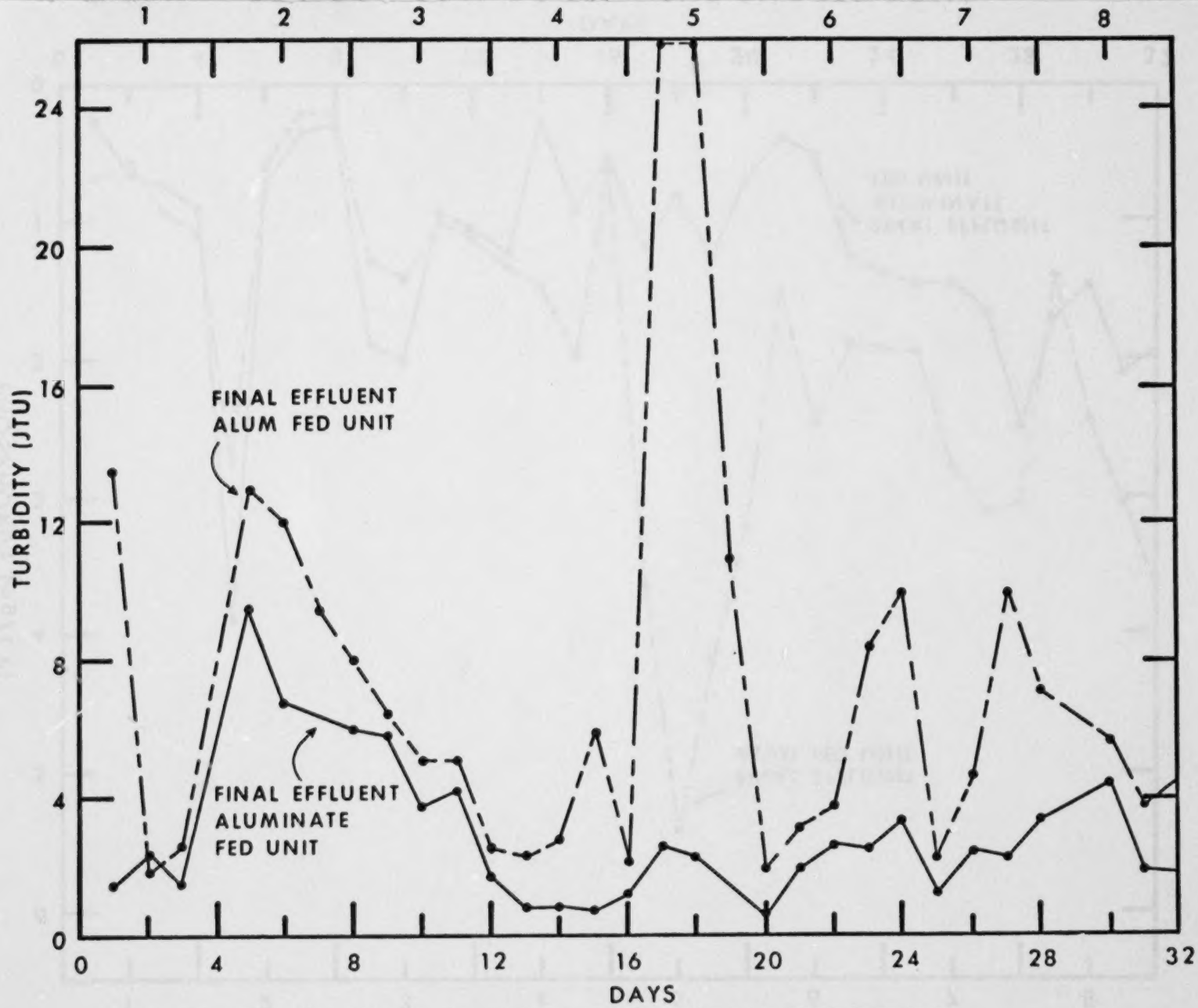


FIGURE 11. COMPARISON OF EFFLUENT TURBIDITY

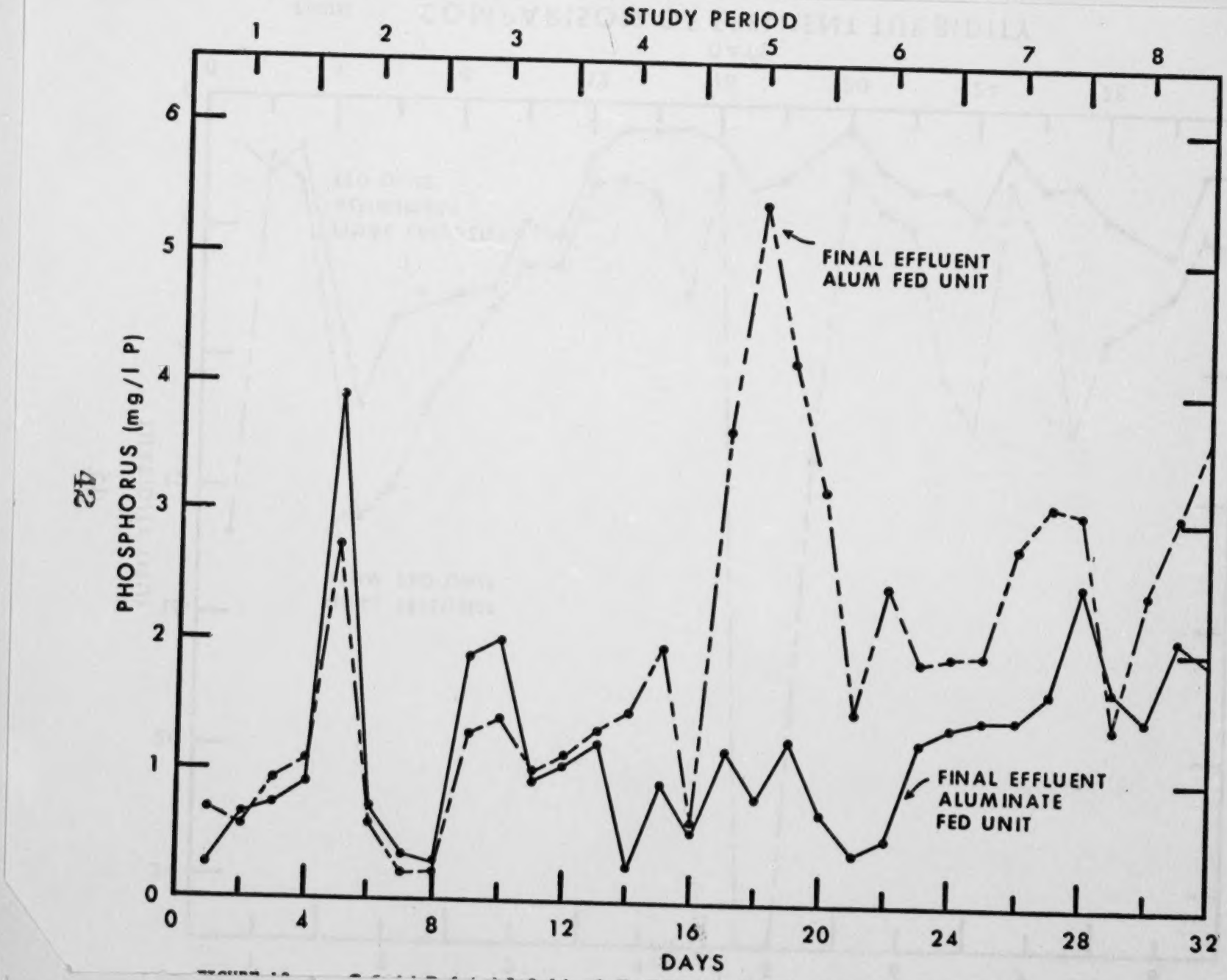

STUDY PERIOD
1
2
3
4
5
6
7
8
PHOSPHORUS (mg/l P)
0
1
2
3
4
5
6
FINAL EFFLUENT
ALUM FED UNIT
FINAL EFFLUENT
ALUMINATE
FED UNIT
0
4
8
12
16
20
24
28
32
DAYS

FIGURE 13.

COMPARISON OF ALUM DOSED AND
ALUMINATE DOSED ACTIVATED SLUDGE UNITS

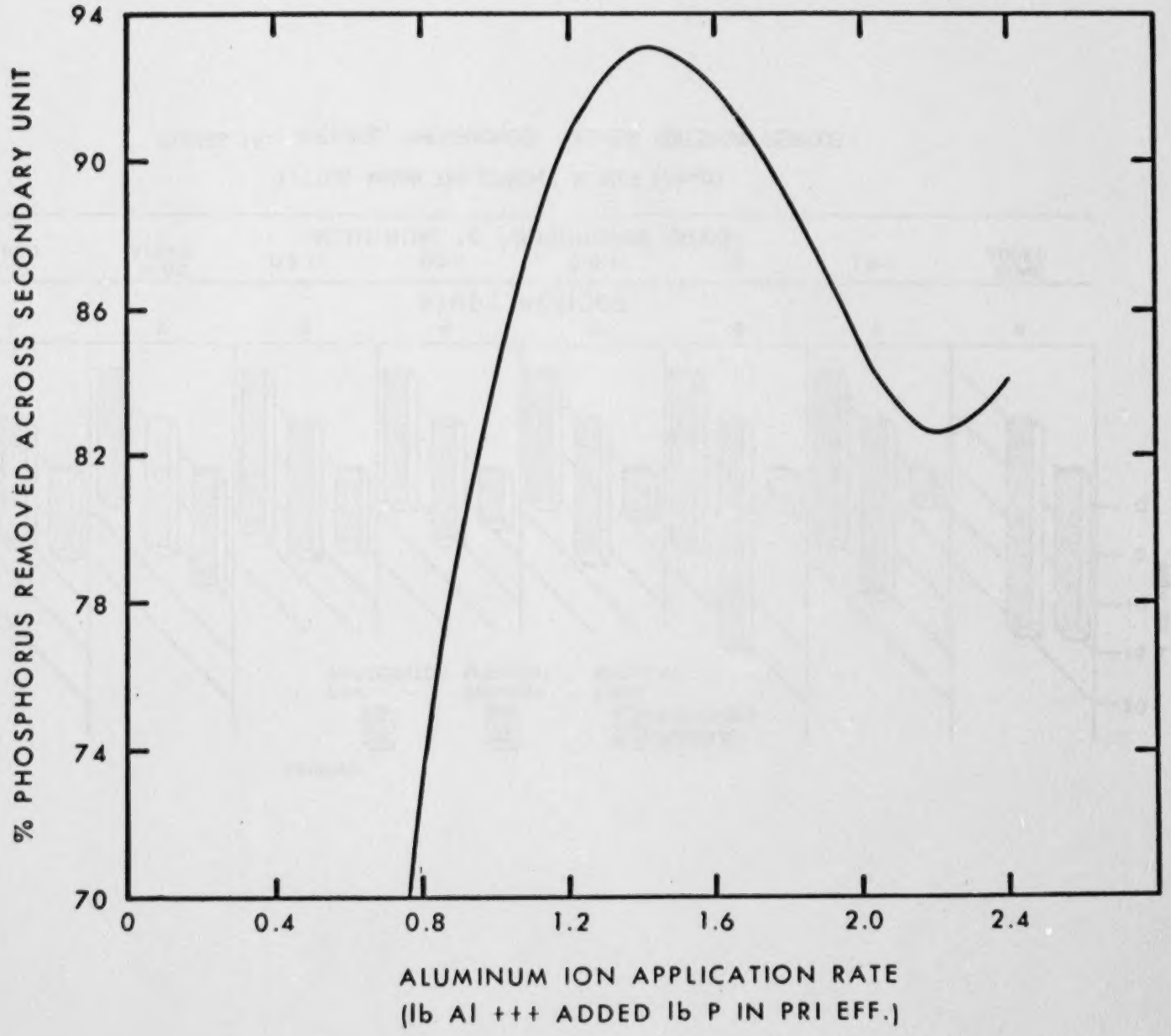
CONSTITUENT	RAW SEWAGE mg/l	FINAL EFF - ALUMINATE DOSED UNIT		FINAL EFF - ALUM DOSED UNIT	
		mg/l	% REMOVAL	mg/l	% REMOVAL
COD	310	23	93	35	89
TOTAL PHOS.	11.6	1.2	90	2.0	83
NITROGEN (ALL FORMS)	23.0	9.4	59	10.7	53
SUSPENDED SOLIDS	157	7	96	21	87
TURBIDITY - PRI EFF - (JTU)	46	3.1	93	7.4	85
ALKALINITY (as $CaCO_3$)	182	165		67	
pH	7.2	7.6		6.9	

FIGURE 14.

POMONA DATA, AVERAGE VALUES

1968 DATE	CHEMICAL ADDED	AL:P RATIO WT./WT.	Phosphorus, mg/l			Percent Removal	
			PRIMARY EFFLUENT	FINAL EFFLUENT (UNFILTERED)	FINAL EFFLUENT (FILTERED)	UNFILTERED	FILTERED
2/12 - 2/26	ALUMINATE	1:1	13.2	2.6	2.1	80	83
2/26 - 3/11	ALUMINATE	1.5:1	13.2	2.3	0.9	83	94
3/18 - 4/1	ALUM	1.1:1	12.8	2.7	2.2	79	83
4/1 - 4/15	ALUM	1.4:1	13.5	1.4	0.7	90	95
4/15 - 4/29	ALUM	1.8:1	13.8	1.5	0.3	89	98
5/13 - 5/27	ALUMINATE	1.5:1	13.2	2.4	1.4	82	90

FIGURE 15.


% PHOSPHORUS REMOVED ACROSS SECONDARY UNIT
94
90
86
82
78
74
70
0
0.4
0.8
1.2
1.6
2.0
2.4
ALUMINUM ION APPLICATION RATE
(lb Al +++ ADDED lb P IN PRI EFF.)

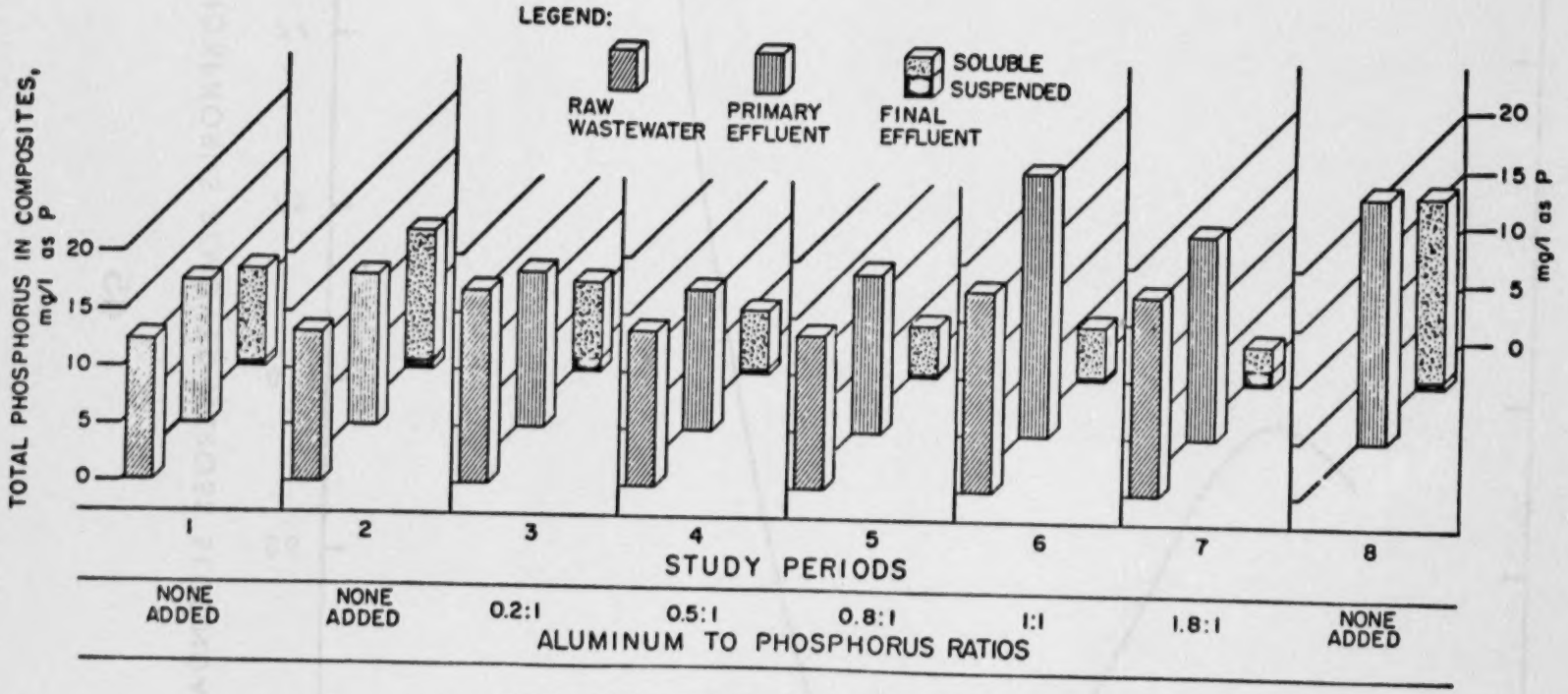
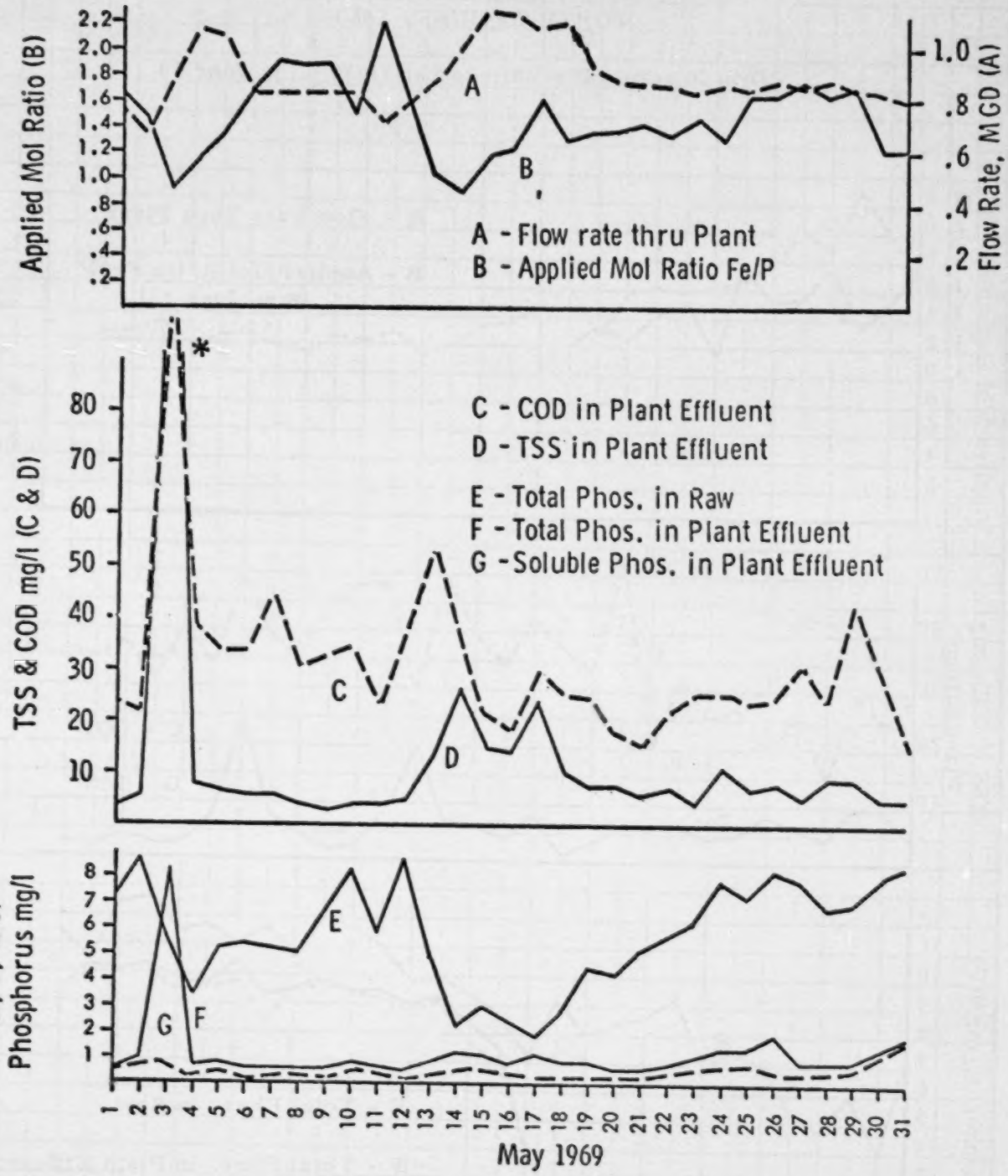


FIGURE 16. AVERAGE PHOSPHORUS VALVES FOR 5-DAY PERIODS



GURE 17. _ Ferrous Iron injection to raw influent, Texas City Plant No. 2 May 1969 *(on May 3 inadvertant acceptance of 1.5-1.6 MGD rate or 2-3 hours, raised effluent COD, suspended solids and phosphorus the day to 108, 141, and 8.3 mg/l respectively.)

FIGURE 18.

FERROUS TREATMENT, TEXAS CITY PLANT No. 2
MONTH OF JUNE, 1969

Iron Injection Discontinued at 11:30 p.m. June 13

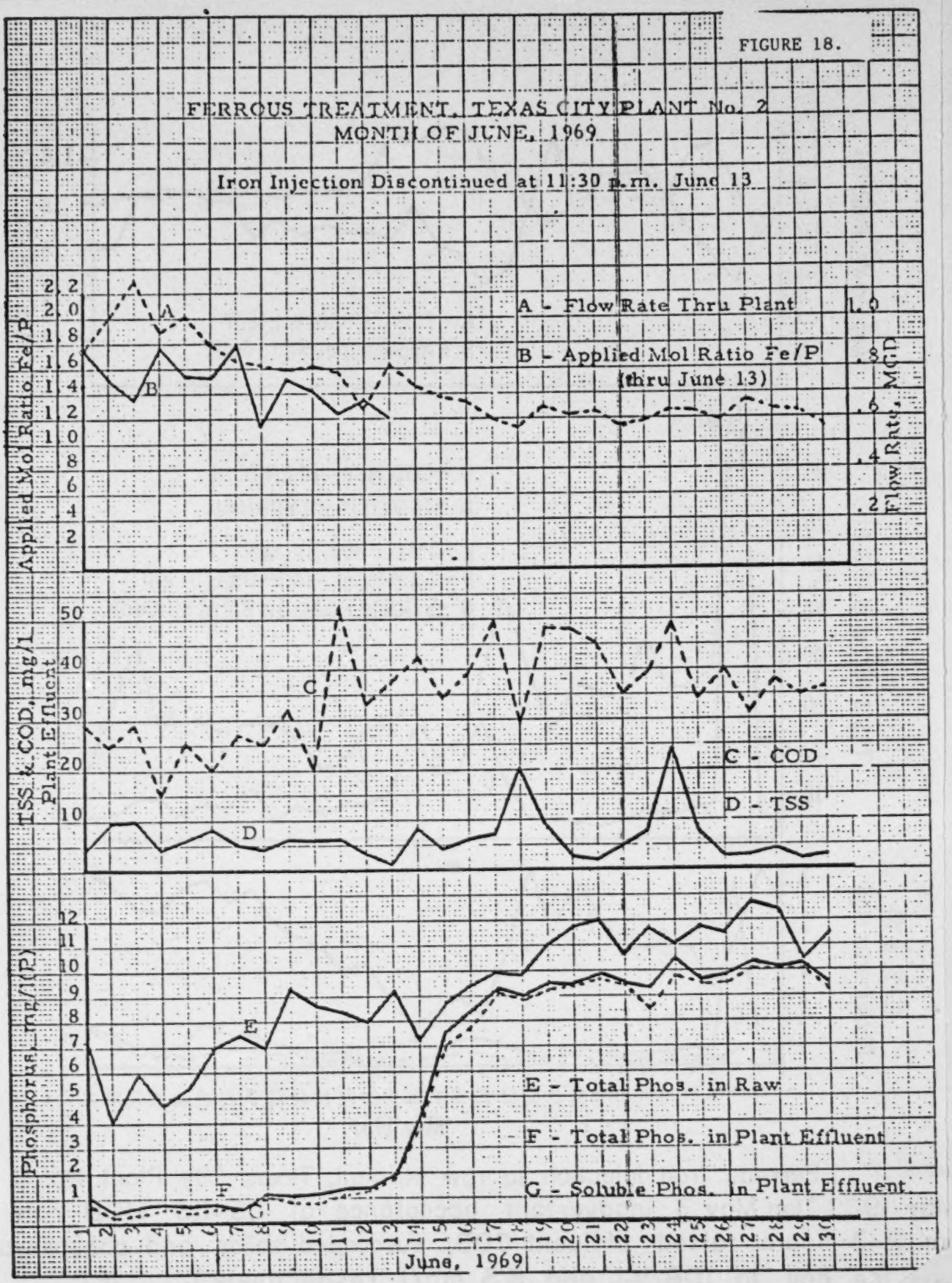


FIGURE 19.

FAIRBORN, OHIO TRICKLING FILTER
(Percent Removals)

Unit efficiency - Primary effluent to final effluent

	Total Phosphorus	COD	S. S.	pH Mode	Al : P
Dosed Filter	63	74	51	7.9	1 : 1
Control Filter	13	75	51	7.8	--

Overall efficiency - Raw waste water to final effluent

	Total Phosphorus	COD	S. S.	pH Mode	Al : P
Dosed Filter	64	83	84	7.9	1 : 1
Control Filter	17	83	85	7.8	--
Entire Plant	37	84	92	7.6	0.3 : 1

FIGURE 20. ADDITION SLUDGE PRODUCED WITH MINERAL ADDITION AT MANASSAS, VIRGINIA

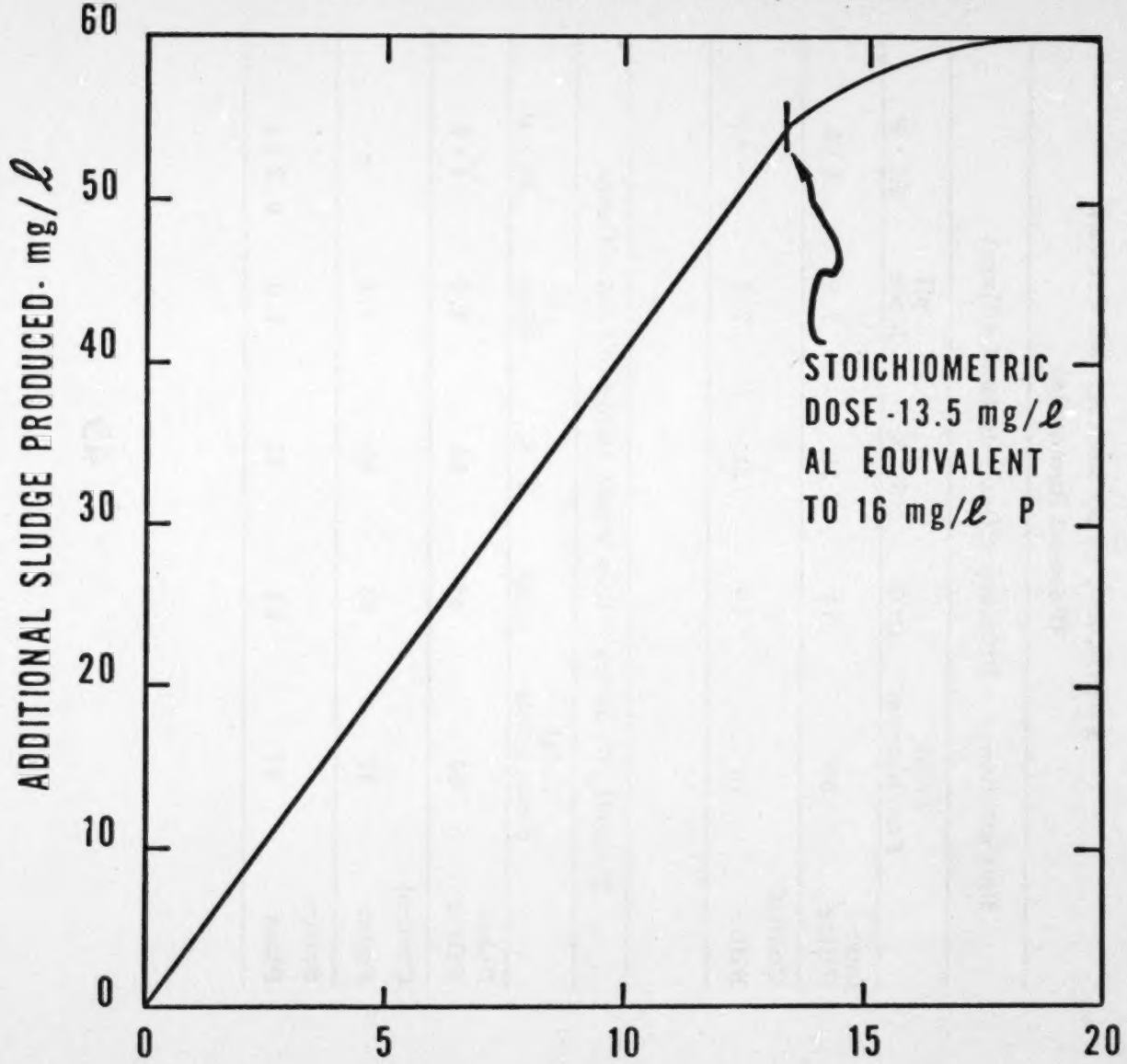


FIGURE 21.

BULK DELIVERED CHEMICAL PRICE STRUCTURE
FOR PROJECTING PHOSPHORUS REMOVAL COSTS

ALUMINUM SULFATE (FREIGHT EQUALIZED)		
1. LIQUID	1.22 cents/lb.	as ALUM
	27.7 cents/lb.	as Al^{+++}
2. DRY	2.87 cents/lb.	as ALUM
	30.8 cents/lb.	as Al^{+++}
SODIUM ALUMINATE (DELIVERED TO SOUTHWEST OHIO)		
1. DRY	12.66 cents/lb.	as ALUMINATE
	36.7 cents/lb.	as Al^{+++}
2. LIQUID	6.42 cents/lb.	as ALUMINATE
	42.5 cents/lb.	as Al^{+++}
QUICKLIME (CaO)	1.15 cents/lb.	
(DELIVERED TO SOUTHWEST OHIO)		

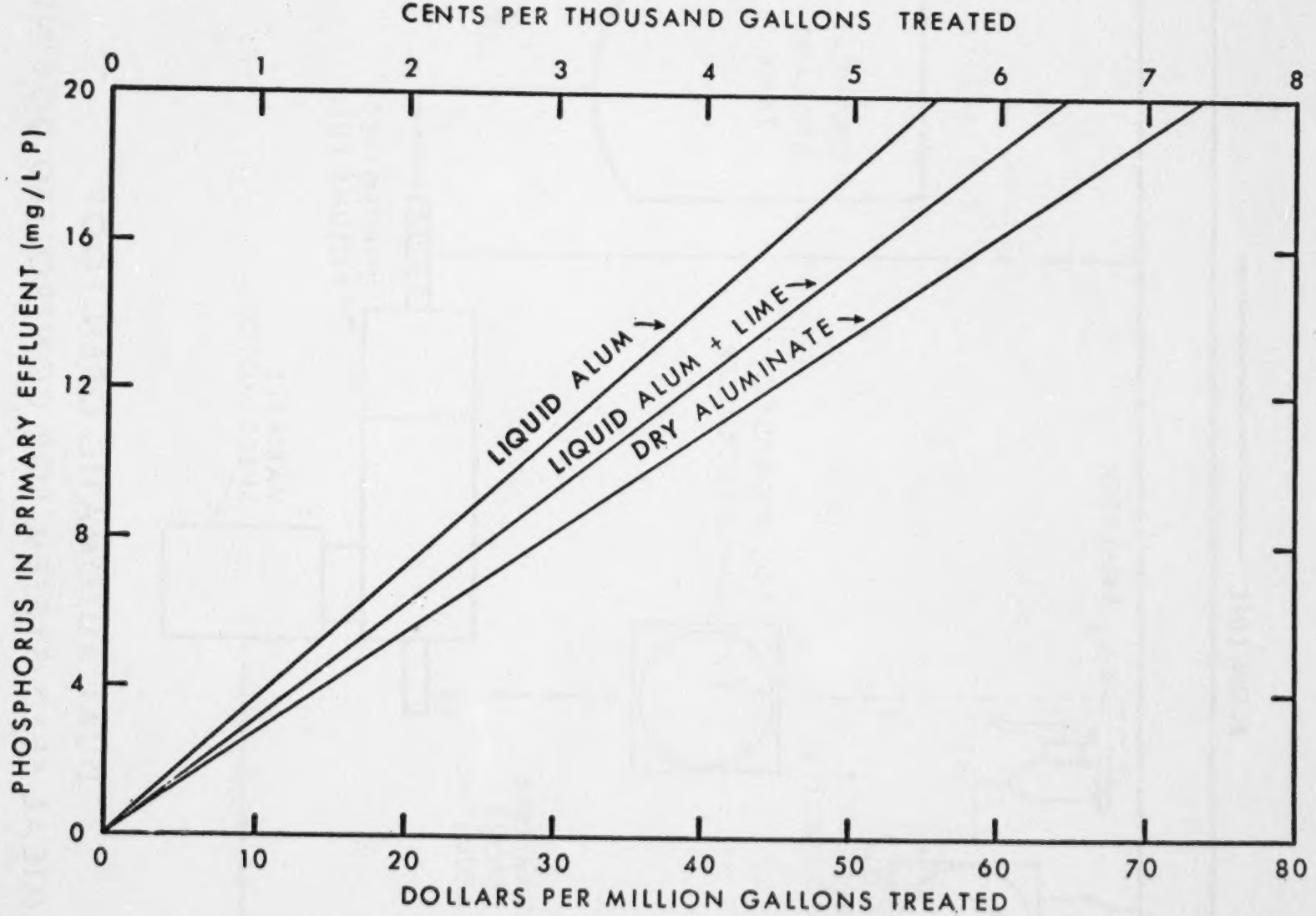
FIGURE 22.

CHEMICAL COSTS OF REMOVING PHOSPHORUS
BY MINERAL ADDITION

BASIS:

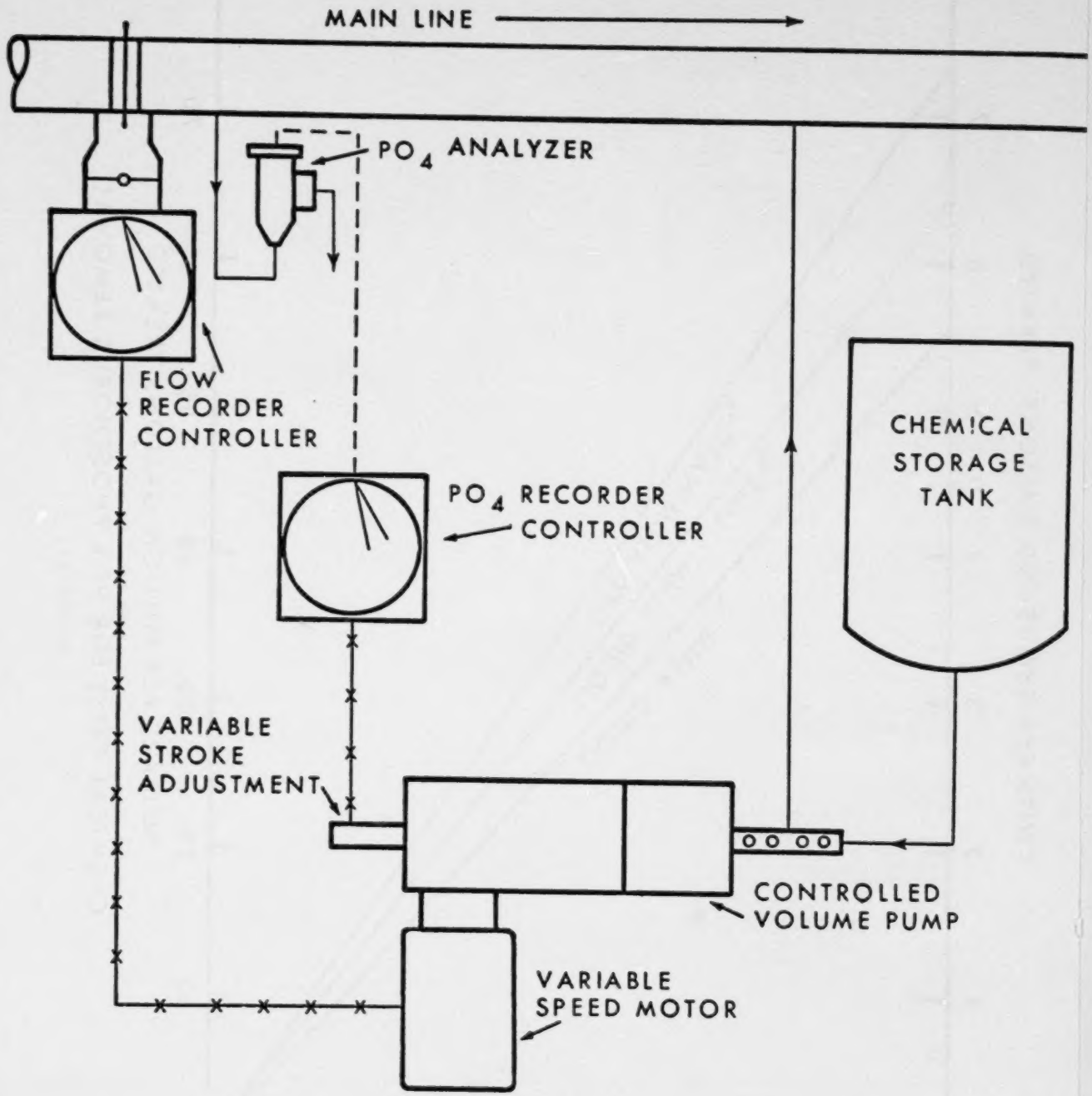
1. PRIMARY EFFLUENT PHOSPHORUS = 10 mg/1 as P.
2. EVERY 5 mg/1 ALUM ADDED (as Al^{+++}) USES UP 34 mg/1 ALKALINITY (as $CaCO_3$).
3. FOR 80% PHOSPHORUS REMOVAL, Al/P = 1/1 BY WEIGHT.
4. FOR 90% PHOSPHORUS REMOVAL, Al/P = 1.2/1 BY WEIGHT.

	ALL COSTS IN DOLLARS PER MILLION GALLONS TREATED	
	80% REMOVAL	90% REMOVAL
LIQUID ALUM	23	28
DRY ALUM	26	31
LIQUID ALUM + LIME	27	32
DRY ALUM + LIME	29	35
DRY ALUMINATE	31	37
LIQUID ALUMINATE	36	43



CHEMICAL COST FOR 90% PHOSPHORUS REMOVAL

FIGURE 23.



DUAL AUTOMATIC OPEN LOOP
CHEMICAL FEED SYSTEM FOR CONTROLLED DOSING

FIGURE 24.

FIGURE 25.

- TOTAL TREATMENT COSTS - ACTIVATED SLUDGE TREATMENT PLUS PHOSPHORUS REMOVAL

COSTS IN DOLLARS PER MIL GAL TREATED

	PLANT SIZE - MGD		
	1	10	100
CURRENT ANNUAL OPERATING COSTS FOR CARBON AND SOLIDS REMOVAL INCLUDING DEBT RETIREMENT	190	120	70
CHEMICAL COST FOR 90% PHOSPHORUS REMOVAL USING LIQUID ALUM - INFLUENT PHOSPHORUS = 10 mg/l P	28	28	28
ADDITIONAL DEBT RETIREMENT AND O & M COSTS FOR PHOS. REMOVAL (ESTIMATED)	15	5	1
TOTAL INCREMENTAL COSTS FOR PHOSPHORUS REMOVAL	43	33	29
TOTAL ANNUAL OPERATING COSTS FOR CARBON, SOLIDS AND PHOSPHORUS REMOVAL (ESTIMATED)	233	153	99
% INCREASE IN TREATMENT COSTS FOR PHOSPHORUS REMOVAL (ESTIMATED)	23	28	42

MODIFICATION OF A TRICKLING FILTER PLANT TO ALLOW CHEMICAL PRECIPITATION

*James E. Laughlin, P. E.

This paper is intended to give the reader information on how a trickling filter waste treatment plant was modified to permit chemical precipitation of phosphorous and other substances. Also, some very preliminary performance data are included from the operational phase of this Advanced Waste Treatment Project.

One performance objective in this project is reduction of phosphorous (as P) to a level of one mg/l or less. Reduction of BOD and suspended solids to 10 or 15 mg/l are further goals of the project. If this plant can perform that well, consistently and economically, a contribution may be made toward enhancing performance of thousands of other trickling filter plants in use today.

Both the modifications described and subsequent performance studies are part of a 28-month Advanced Waste Treatment Project. Physical modifications are complete. Operational investigations are underway and will continue through 1971. By early 1972 it should be possible to assess whether the modifications were well conceived, and whether the process can be optimized and made part of the plant operating procedure. The appendices to this paper

---

*Partner, Shimek-Roming-Jacobs & Finklea, Consulting Engineers, Dallas, Texas

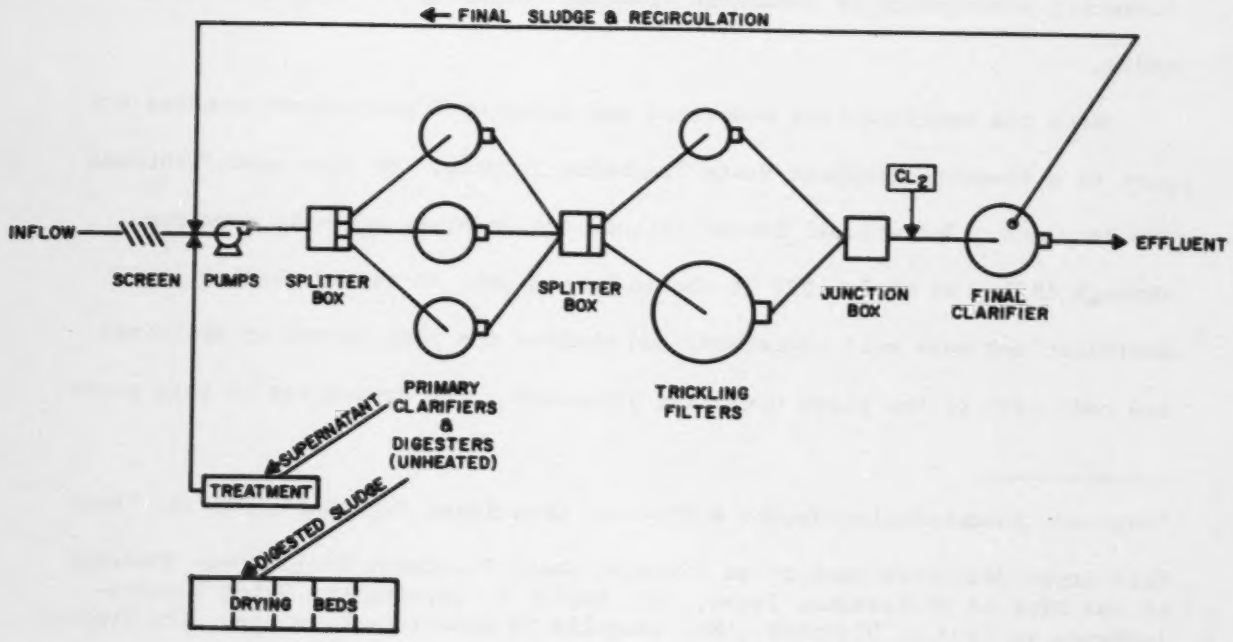
This paper describes part of an Advanced Waste Treatment Project now underway at the City of Richardson, Texas. Mr. Robert E. Derrington, Water Superintendent, is Project Director. Mr. Laughlin is Associate Director. The project is 75% funded by the Environmental Protection Agency.

include the project schedule, and background on generation and processing of data.

EXISTING TREATMENT FACILITIES

In this project, chemical treatment is intended as an adjunct to the typical physical and biological treatment already provided. Furthermore, it was intended that required modifiçations be as simple as possible and that existing facilities be fully utilized. The plant's existing facilities can be shown in a schematic sketch. Design capacity is 1.6 MGD.

CITY OF RICHARDSON, TEXAS
WASTEWATER TREATMENT PLANT
1969



A mechanical bar screen precedes a wet well serving four raw sewage pumps which lift the water into a flow splitter box. Proportional weirs there divide flow between three clarifier-digesters. Primary effluent is combined in a splitter box, then divided and sent to two standard rate rock filters. Filter effluent is combined and carried to the final clarifier. Chlorination and settling are simultaneous in that clarifier. A mixture of final sludge and recirculation are returned to the head of the plant; the amount of recirculation is regulated by a level control system in the raw sewage wet well.

Sludge is digested in the lower compartment of each primary clarifier-digester. No heat is provided (gas is wasted through a burner) and mixing consists of gentle stirring by a 3 rph mechanism revolving on the same shaft as the clarifier rakes above.

Sludge is dried on sand beds. Filtrate collected in the underdrains goes back to the head of the plant. Digester supernatant is drawn and batch treated before return to the head of the plant. Three 500 gallon fill-and-draw tanks receive raw supernatant; alum is added, 250 mg/l, then 20 minutes of air agitation yield a finished liquor which separates into sludge (which goes onto drying beds) and treated supernatant with strength comparable to raw sewage.

Detailed plant data can be condensed into the table which follows.

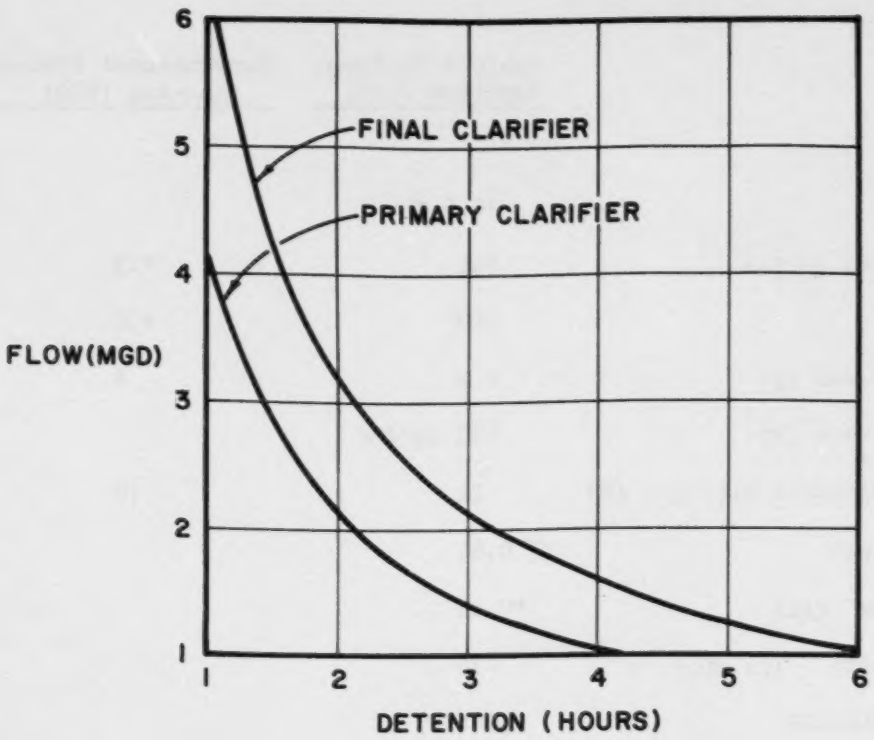
DATA ON TREATMENT UNITS

	Diam (Ft)	Depth (Ft)	Circum (Ft)	Area (Sq Ft)	Volume (Cu Ft)	Volume (Gal)
Primary Clarifier No. 1	40	8	126	1257	10,054	75,200
2	40	10	126	1257	12,570	94,000
3	40	10	126	1257	12,570	94,000
Primary Clarifiers Combined	--	--	378	3771	35,194	263,200
Final Clarifier	70	6	220	3848	23,088	173,000
Filter No. 1	84	6.5	--	5542(1)	36,000	--
2	120	6.5	--	11310(1)	73,500	--
Filters Combined	--	--	--	16852(1)	109,500	--
Digester No. 1	40	14.3(2)	--	1257	13,000	135,000
2	40	14.3(2)	--	1257	13,000	135,000
3	40	14.3(2)	--	1257	13,000	135,000
Digesters Combined	--	--	--	--	39,000	404,000

Sludge Drying Beds 12,000 Square Feet

(1) Area in acres: 0.127, 0.260 and 0.387, respectively
(2) 14.3 Effective, 18.0 SWD, 15.8 Clear @Center

These physical dimensions allow estimation of clarifier detention times at different flows, an important factor in predicting lag time through the plant. Hyperbolic equations describing assumed plug flow are plotted on the following graph.



Although the plot is only an approximation of actual conditions (and this is further compounded when assuming plant detention time equals cl detention time), it has proven most helpful in predicting passage of n conditions through the system.

The following table summarizes data on the load received at the existing plant, and on the performance of the system.

CHARACTERISTICS OF WASTEWATER
(mg/l unless noted)

	Typical Influent (Apr-Nov 1970)	Conventional Effluent (Apr-Aug 1970)
Flow	*1.6 MGD	
Suspended Solids	145	*15
BOD	140	*20
Phosphorous (p)	8.8	8
Phosphorous (P)	122 lb/day	
Total Kjeldahl Nitrogen (N)	21	10
Iron (Fe)	0.84	
Aluminum (Al)	*0.23	
Alkalinity (Ca CO_3)	175	
Ratio BOD/COD	0.45	

*Geometric means, all other values are arithmetic means.

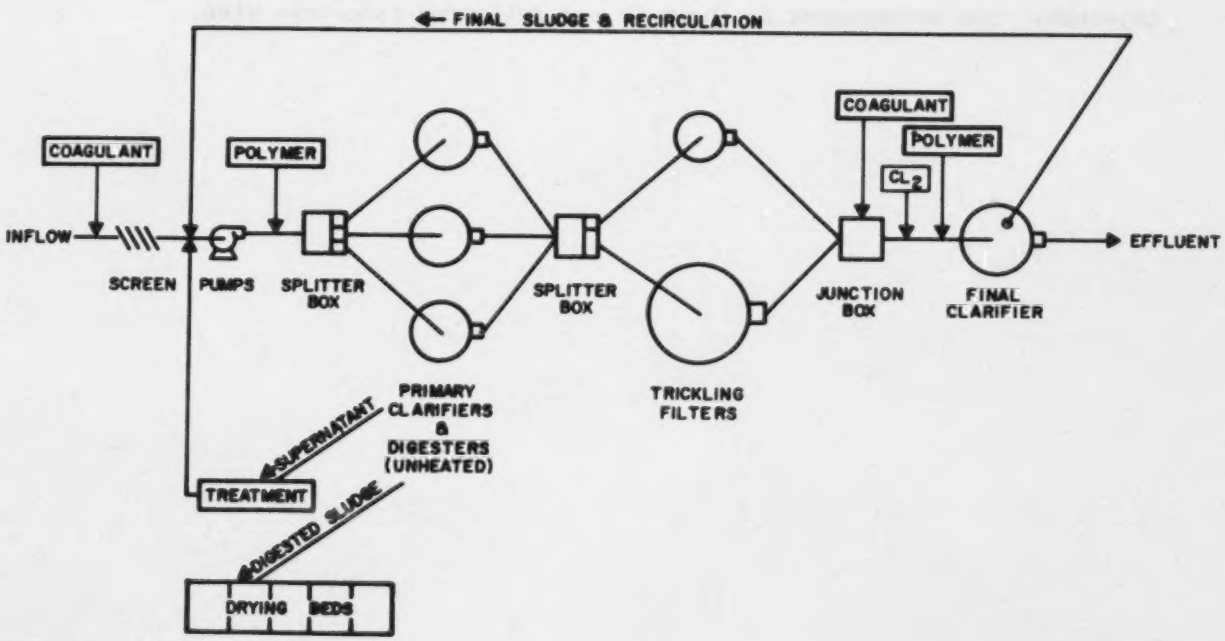
Richardson's treatment plant has been attended full time for some years. Approximately 320 manhours per week are required to operate and maintain the facility. In addition, an analyst devotes 40 man hours per week in the control laboratory.

MODIFICATION FOR CHEMICAL ADDITION

Early in the project two coagulants were selected for operational trials: aluminum in the form of liquid alum, and iron in the form of liquid ferric chloride. Both are available in bulk, from commercial firms, at haul distances of about 250 miles. Both are similar enough in character to permit use of common storage and feeding hardware. Use of polymers was also predicated at this point, assuming they would be worthwhile in improving settling characteristics of solids involved.

The flow diagram of the plant could now be modified to permit addition of these chemicals at the head end and just ahead of the final clarifier.

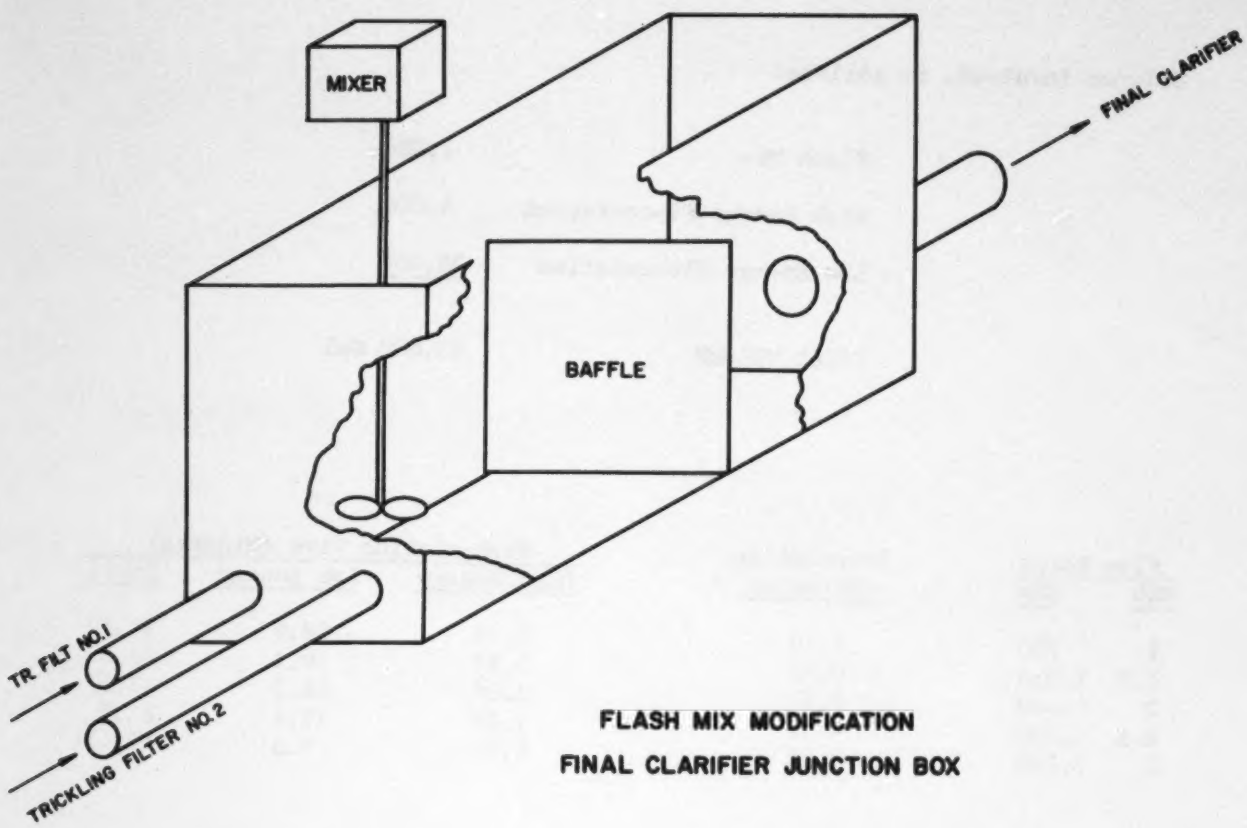
CITY OF RICHARDSON, TEXAS
WASTEWATER TREATMENT PLANT
1970



One 6000 gallon fiberglass stores liquid coagulant in a central location. Two chemical feed pumps are installed beside the tank, and piped to deliver to either the head or effluent ends of the plant, or both ends simultaneously. Both pumps have variable feed controls covering their 0-110 gph discharge range. Pump controls have automatic-manual capability. Wetted parts are of materials resistent to alum and ferric chloride.

Two 1200 gallon fiberglass polymer storage tanks are provided: one near the plant influent sewer and the other near the final clarifier. Both have feed pumps similar to the pair at the coagulant tank. In addition, polymer tanks have eductor assemblies for dispersing polymer, and 3 hp mixers for blending fresh batches of polyelectrolytes.

The junction box preceding the final clarifier was modified to provide flash mixing of coagulant. The change involved baffling off a section and installing a mixer there to promote rapid dispersal of the metal salts injected. The arrangement is shown in the following isometric view.



FLASH MIX MODIFICATION
FINAL CLARIFIER JUNCTION BOX

The mixer delivers 2.2 water hp. The approximate velocity gradient for this system is G equals 650/sec. At the average flow of 1.6 mgd, detention is some 50 sec, so Gt equals 32,000.

Further analysis of this dispersion-flocculation system gives information on the reaction times available for flash mixing, intense flocculation, and gentle flocculation. These detention periods are based on simple displacement through: mixing chamber, pipeline, and that part of the centerwell area in the clarifier where active flocculation is observed.

Volumes involved, in gallons:

Flash Mix	1,000
High Energy Flocculation	4,000
Low Energy Flocculation	20,000
TOTAL VOLUME	25,000 Gal

Flow Rates MGD	Flow Rates GPM	Coagulation (Minutes)	Flocculation Time (Minutes) High Energy	Low Energy	Total
1	700	1.42	5.71	28.6	34.3
1.5	1,050	0.95	3.81	19.1	22.8
2	1,400	0.71	2.86	14.3	17.1
2.5	1,750	0.57	2.28	11.4	13.7
3	2,100	0.48	1.91	9.5	11.4

Flash mixing of coagulants added to raw sewage uses kinetic energy of the turbulant flow entering the wet well. Chemicals are injected at a manhole; mixing begins in a ten feet section of steeply descending sewer which carries plant inflow to the wet well, and dispersal is completed in a confined receiving zone in the wet well.

After a brief (and indeterminant) stay in the wet well, flow is picked up by pumps and passes into the splitter box. Detention time is short and energy levels are fairly high from pumps to clarifiers. All this is followed by flocculation in the centerwell area of the clarifiers, but an estimate of the size of the flocculation zones there has not been possible.

Summarizing, coagulant dispersal and flocculation in raw sewage takes place at ill-defined energy levels and reaction periods. The arrangement

is probably not as effective as that in the final effluent, but there has been an attempt to make the best of the existing situation.

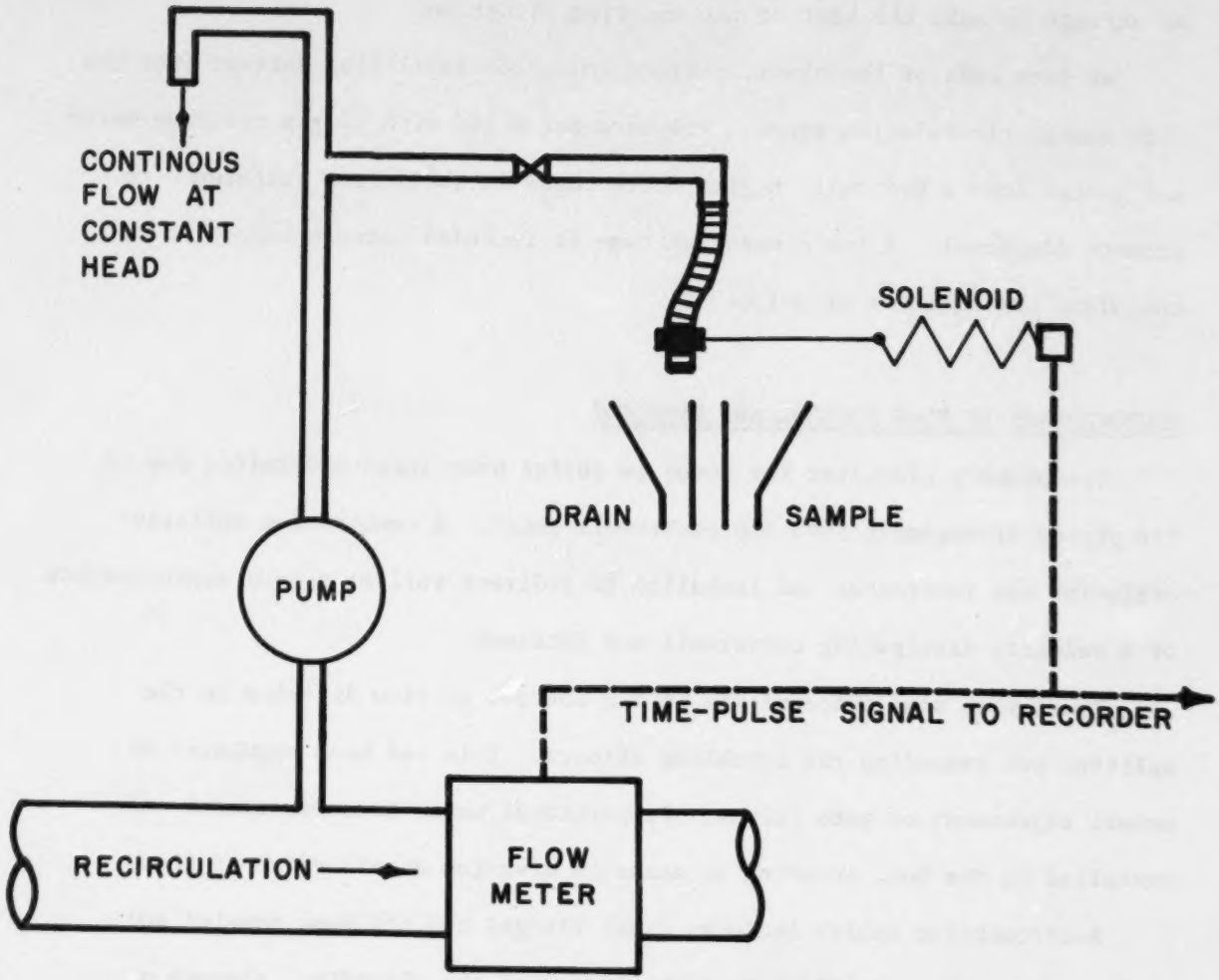
At both ends of the plant, polymer injection facilities deliver into the high energy rlocculation zones. Polymers are mixed with 20 gpm carriage water and jetted into a hydraulic regime where there is sufficient turbulence to promote dispersal. A two minute lag time is intended between injection of coagulant and addition of polymers.

IMPROVEMENTS IN FLOW CONTROL AND SAMPLING

One primary clarifier was found to suffer poor inlet hydraulics due to its piping arrangement into the centerwell skirt. A combination splitter-deflector was fabricated and installed to redirect inflow; a good approximation of a velocity dissipating centerwell was obtained.

There were some inaccuracies in the control of flow division in the splitter box preceding the trickling filters. This had been regulated by manual adjustment of gate valves. Proportional weirs were fabricated and installed in the box, insuring an accurate division at all rates of flow.

Recirculation (which includes final sludge) had not been sampled and tested previously. It flows from the bottom of the clarifier, through a gravity line, to the raw sewage wet well. There is a vault housing a flow meter and an air-operated throttling valve at the midpoint of the line. Facilities for automatic sampling were installed in the vault, and function per the following sketch.



RECIRCULATION SAMPLER

A continuous sample flow is withdrawn and split between a constant head shunt and a sample shunt which normally is directed to drain. When the flow meter generates a signal indicating flow in the recirculation line, that signal energizes a solenoid which diverts sample flow to a receiving can. The amount of sample caught is proportional to the amount of recirculation flow.

Two magnetic flow meters were added to the supernatant treatment system: one measures raw flow coming in, and the other measures treated supernatant going to the head of the plant. The difference between their cumulative readings gives the volume of precipitated sludge diverted to drying beds.

The throttling valve on the plant recirculation line had, for years, been controlled by water level in the wet well. Recirculation occurred on a demand basis. For reasons discussed later it became necessary to sharply reduce this flow. An electric timer was wired into the control circuit in a manner which allowed it to override other signals. This timer was eventually set to trigger a 25 second flushing flow every 20 minutes; this pattern established a 70,000 gpd recirculation rate.

Underdrain facilities at the sludge drying beds collect filtrate from wet sludge. Underflow from seven beds comes to either of two filtrate manholes. The manholes were partially dammed and a sump pump was placed in each. A standard water meter was put into the discharge line of each pump, and this permits a record of bed drainage.

A static head of nearly 15 feet of water is available to push digested sludge from digesters to drying beds. This gravity arrangement appears entirely suitable from an operational standpoint. For this project, however, an accurate measure of sludge flow is needed. A piston type sludge pump, with

attached stroke counter, was installed for that reason.

MISCELLANEOUS IMPROVEMENTS

A small manually adjusted chlorinator had served the plant adequately for some years. It was replaced by an automatic 2000 ppd unit with compound-loop automatic controls. This changeout was made more to support the demonstration project than it was to modify the plant for chemical addition. Also, after trial operations the waste flow sensing leg was disconnected in the compound-loop control; chlorine flow can be closely controlled by the automatic residual analyzer.

A recording pH meter was installed to monitor plant influent, and a recording dissolved oxygen meter was set up on the effluent. Both of these supply information valuable to the demonstration project, but neither would be really necessary in a normal plant modification.

Ten small pipelines, mostly PVC, were installed at various locations around the plant. These deliver coagulant, polymer dilution water, diluted polymer, rinse water, and sample flows.

Prior to the project, all three digesters were drained and cleaned. Steel stirring mechanisms were strengthened or rebuilt as necessary. This insured that the digestion system was free of grit and was mechanically functional for the study.

LABORATORY FACILITIES AND PERSONNEL

The existing plant had its control laboratory located in the main building. The arrangement was somewhat cramped, so a separate lab building was built just

prior to beginning the project. Additional space and personnel were added to support the study.

There are thirteen sampling points in the treatment plant, and up to twenty-three analyses may be run on the composite samples taken. Appendix B shows the stations and analyses involved. Approximately 140 items of data are reported on each sample day.

A staff of three analysts works five days per week, usually Monday through Friday. The samples they run are those collected Sunday through Thursday. Occasionally they work on weekends to gain data on samples collected Friday and Saturday. A fourth analyst, who works about 30 hours a week, helps handle the heavy lab load involved in the project.

Lab effort related solely to the project includes a statistical quality control program to verify data, zeta and jar test studies on coagulants and polymers, total and fecal coliform tests, turbidity, COD, and a broad range of analyses to trace buildup or removal of particular substances.

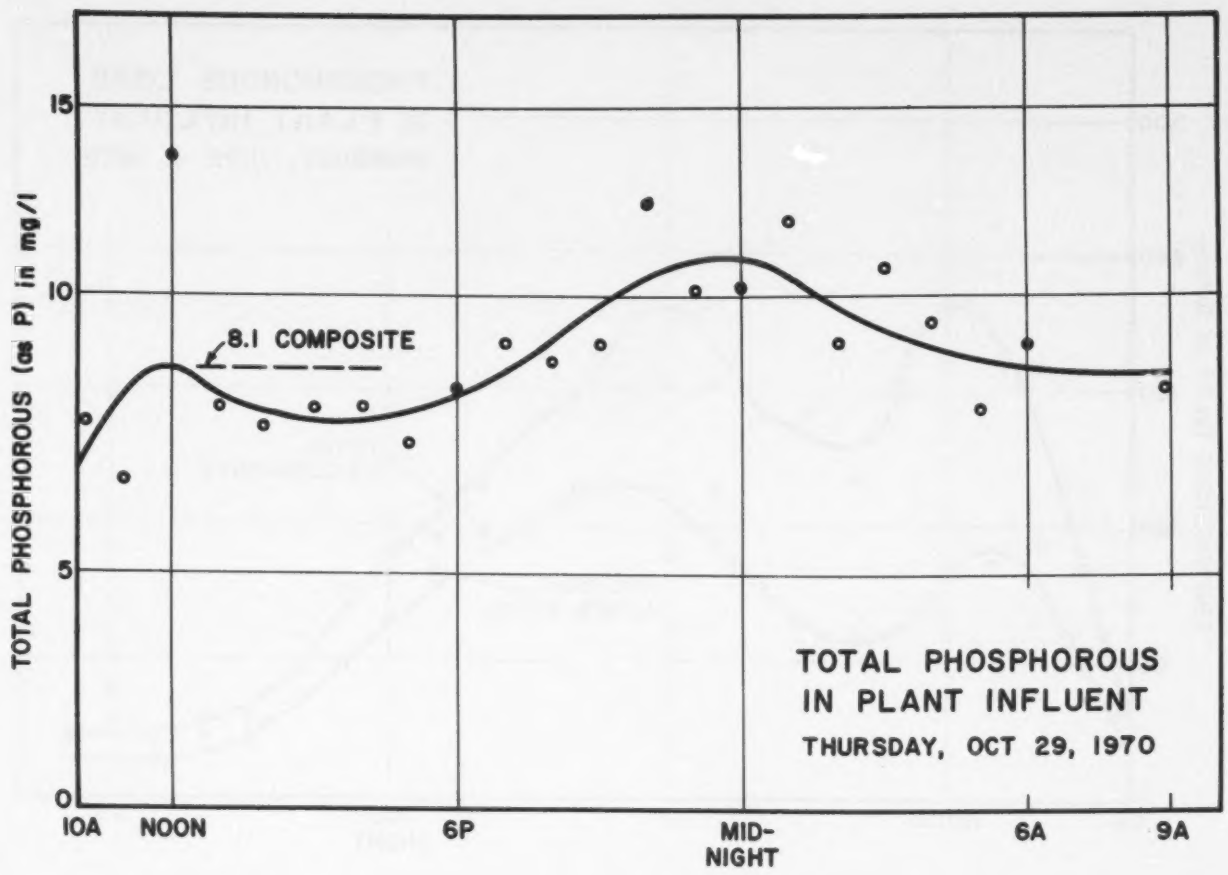
From a strict standpoint of normal operational control of chemical precipitation, the typical tests for a conventional plant (BOD, solids, pH, temperature, dissolved oxygen) should be supplemented by phosphorous, alkalinity, and perhaps elements involved in the coagulant (iron or aluminum, and sulfate or chloride). Some phosphorous tests should be made on hourly grab samples, as discussed later. The other tests would be run on daily composites. Also, jar tests would be needed to guide determination of proper chemical feed; these would be similar to those required in a water treatment plant.

A final category of tests has been run routinely for some time: various nitrogen forms and sulfides. Whether these are required for operational control at other plants would be a matter of individual judgement.

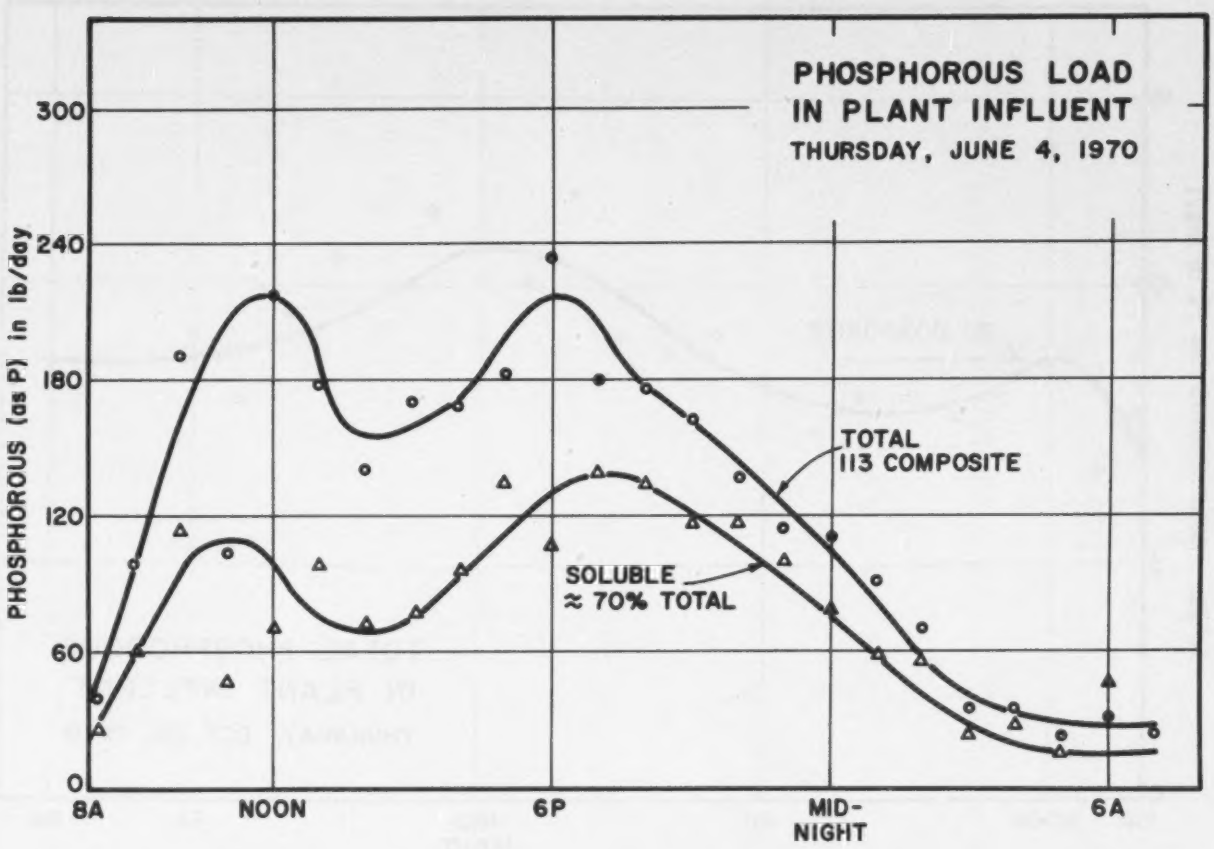
PRELIMINARY OPERATIONAL RESULTS

Liquid alum was added during waste treatment in the fall of 1970. Considerable data were taken and are still being analyzed. This information has scant value until the study is finished and put into perspective. It seemed proper to share some of the data, with the understanding that THESE ARE PRELIMINARY OBSERVATIONS---NOT DEFINITIVE CONCLUSIONS. Readers should appreciate this point and temper their views accordingly.

To begin, two illustrations show typical values of phosphorous coming into the plant. The first plots phosphorous concentration based on hourly samples.


TOTAL PHOSPHOROUS (as P) in mg/l
15
10
5
0
8.1 COMPOSITE
TOTAL PHOSPHOROUS
IN PLANT INFLUENT
THURSDAY, OCT 29, 1970
10A
NOON
6P
MID-
NIGHT
6A
9A

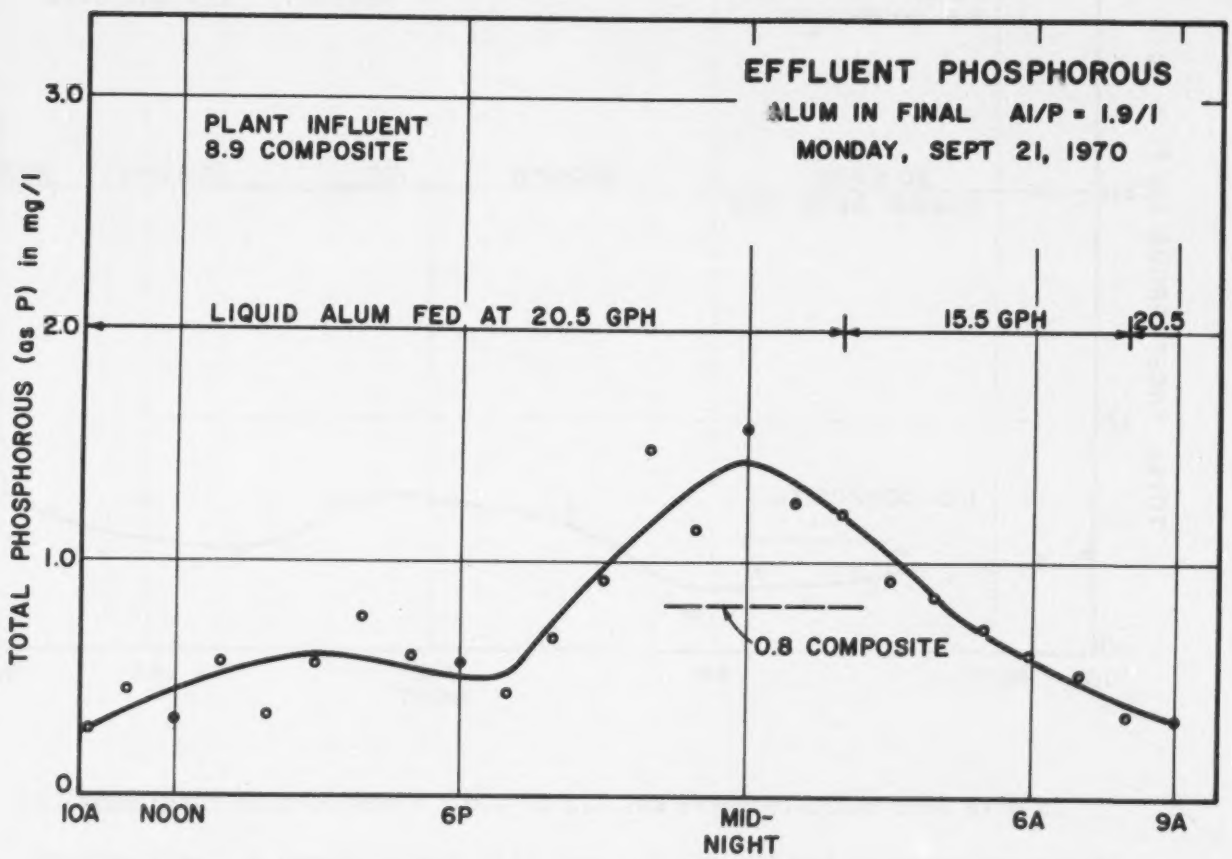
Composite phosphorous income (as P) was 8.1 mg/1, slightly less than the statistical mean. The next plot shows typical phosphorous load (1b/day) and shows the soluble fraction.



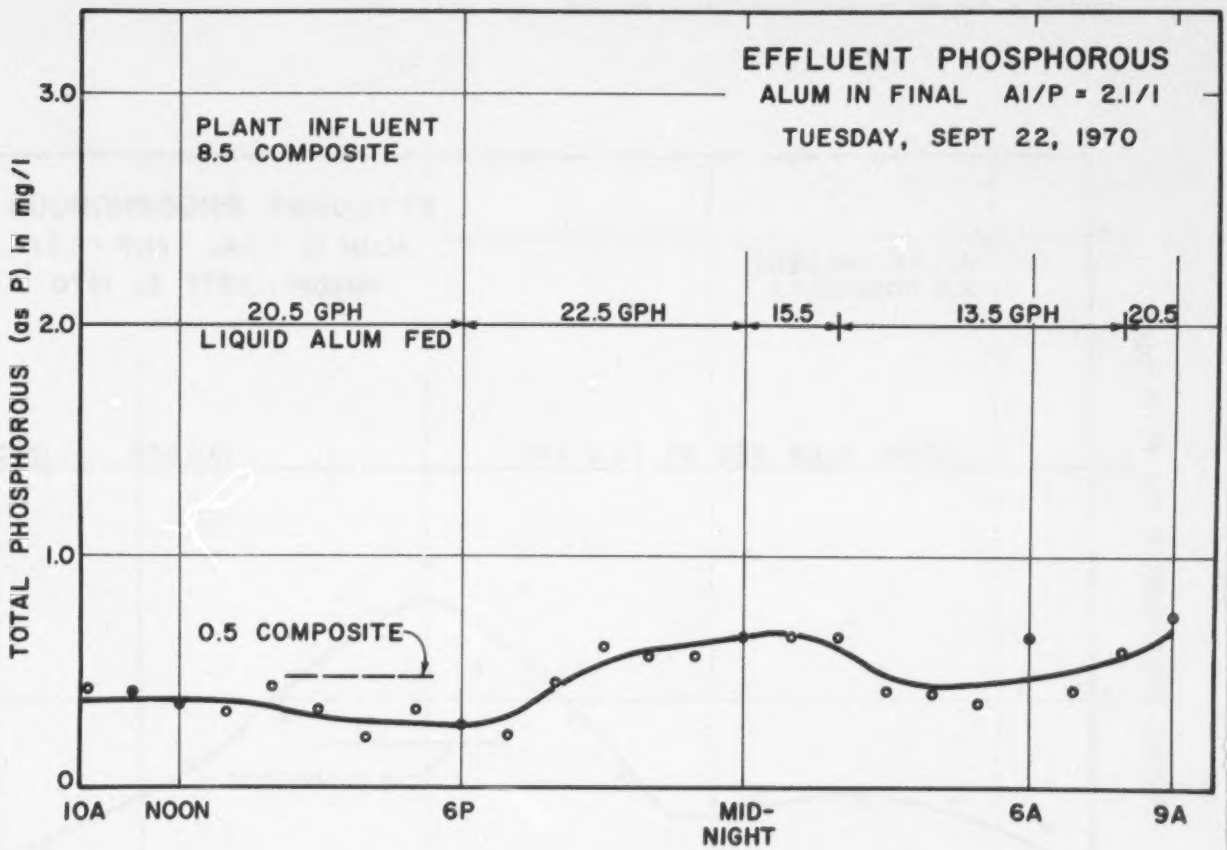
Total phosphorous in the composite was 113 lb/day. The soluble fraction was 70%, a ratio which is believed consistent.

During September liquid alum was added to flow entering the final clarifier. After a period of fixing leaks in chemical delivery pipes, recalibrating chemical

pumps, and other startup activities, some proper results developed. Two key items were learned: hourly effluent grab samples are vital to regulation of feed rates, and low recirculation rates (70,000 gpd) are necessary to preserve the floc blanket which develops around the centerwell. When the blanket is present, effluent is clear and low in phosphorous, BOD, and suspended solids. When the blanket is absent, results suffer. The next plot shows performance during a day when two chemical pump settings were used.



Notice the mole ratio of aluminum to total phosphorous was 1.9 to 1.0. Phosphorous levels in plant inflow were normal. Effluent phosphorous got out of control near midnight, and the mean effluent concentration that day was 0.8 mg/1. This performance led to changing chemical feed rate five times per day, and resulting improvements are shown in the next graph.

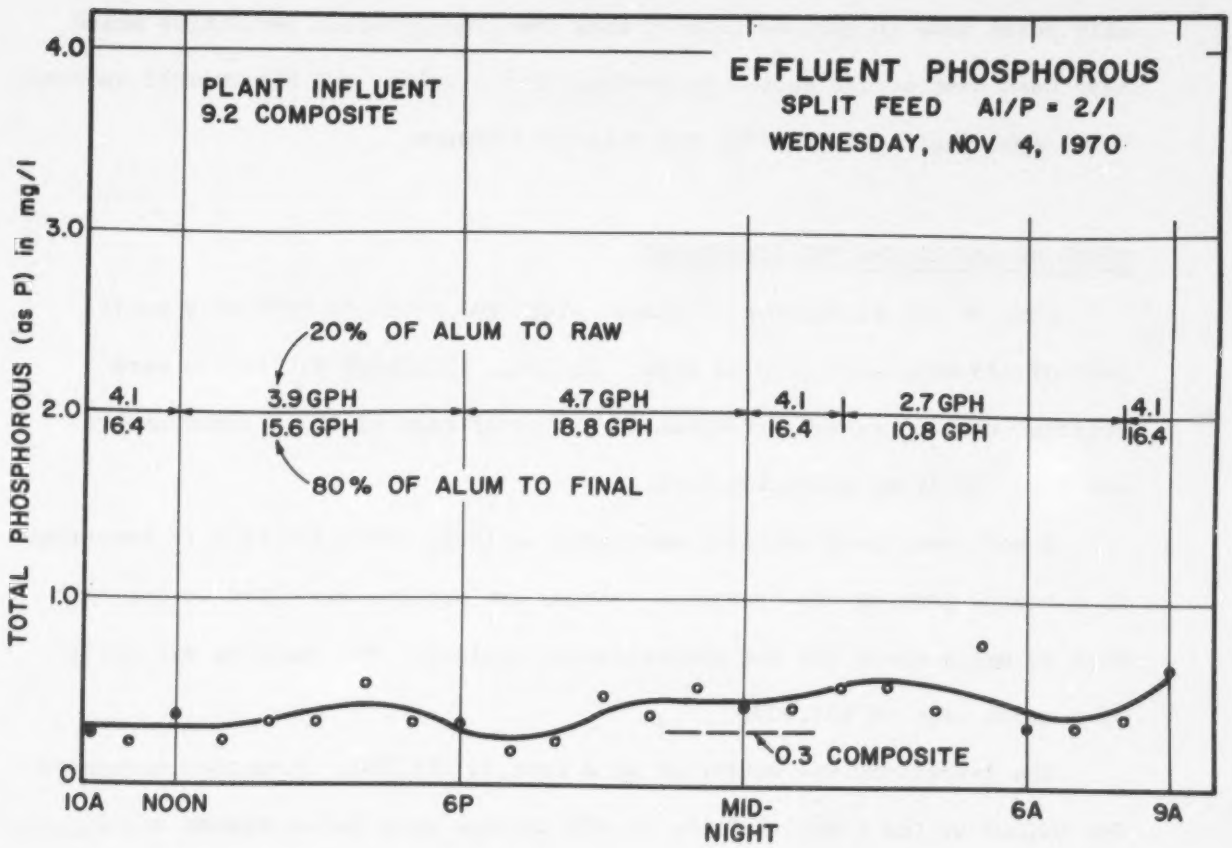


In this case the mole ratio was 2.1 to 1.0. There were no sharp peaks in effluent phosphorous levels, and the composite sample showed 0.5 mg/1 escaped.

At this time it is felt that multiple settings of chemical pumps are vital to good performance with minimum alum consumption.

In October alum was added to raw sewage. Performance seemed not as good as before, and signs of digester overloading led to termination after nine days of trial. No data or further comments can be offered at this point.

In November split feeding (to raw and final) was tried. The following figure shows results of one of the better days.



Feed was 20% to raw and 80% to final. The mole ratio was 2 to 1. Composite samples showed phosphorous was 9.2 mg/l in plant influent and 0.3 mg/l in the effluent.

The preceding plots illustrate performance on some of the better days to date; there are indications that good results can be gotten day after day, but this point lacks proof. Further, it has not been proven that digesters can accept increased loads (from any of the feed regimes) on a long term basis. The changes in character of digested sludge have not been properly studied. Much data already collected is not discussed here. More data is needed. The only point made in this section is that the precipitation facilities which have been used so far appear to perform mechanically, and the overall approach holds some degree of hope for reliable performance.

COSTS OF FACILITIES AND OPERATIONS

Part of the Richardson treatment plant was built in 1953 at a total cost of $75,000, exclusive of land. In 1961, treatment facilities were enlarged to the present arrangement; the total cost of those improvements was $0.25 million, excepting land.

A new laboratory building was added in 1969. This facility is considered an integral part of the treatment system, but perhaps one-third of its cost went to extra space for the demonstration project. The building was built at a total cost of $33,000.

The laboratory was outfitted at a cost of $11,000. Furniture accounted for $2,000 of the total, and the $9,000 balance went for equipment and supplies.

Some of the equipment might not be required except for the demonstration project: a $3,000 zeta meter, a $600 recording pH meter to monitor plant inflow, a $700 recording dissolved oxygen meter to monitor effluent, and some $700 worth of special glassware and chemicals. The remaining $4,000 would have been spent for laboratory facilities to support chemical coagulation in the treatment plant; major items include $800 for an advanced type of jar test apparatus, an $800 analytical balance, and a $500 spectrophotometer.

If the laboratory had been built solely to support chemical coagulation in the treatment plant, it would have cost about $21,000 for the building and $6,000 for furniture, equipment, and apparatus.

Modifications to the treatment plant came to a total cost of $53,000 distributed as follows:

Materials	$35,000
Labor	7,000
Supervision	3,500
Design and Misc.	7,500
TOTAL	$53,000

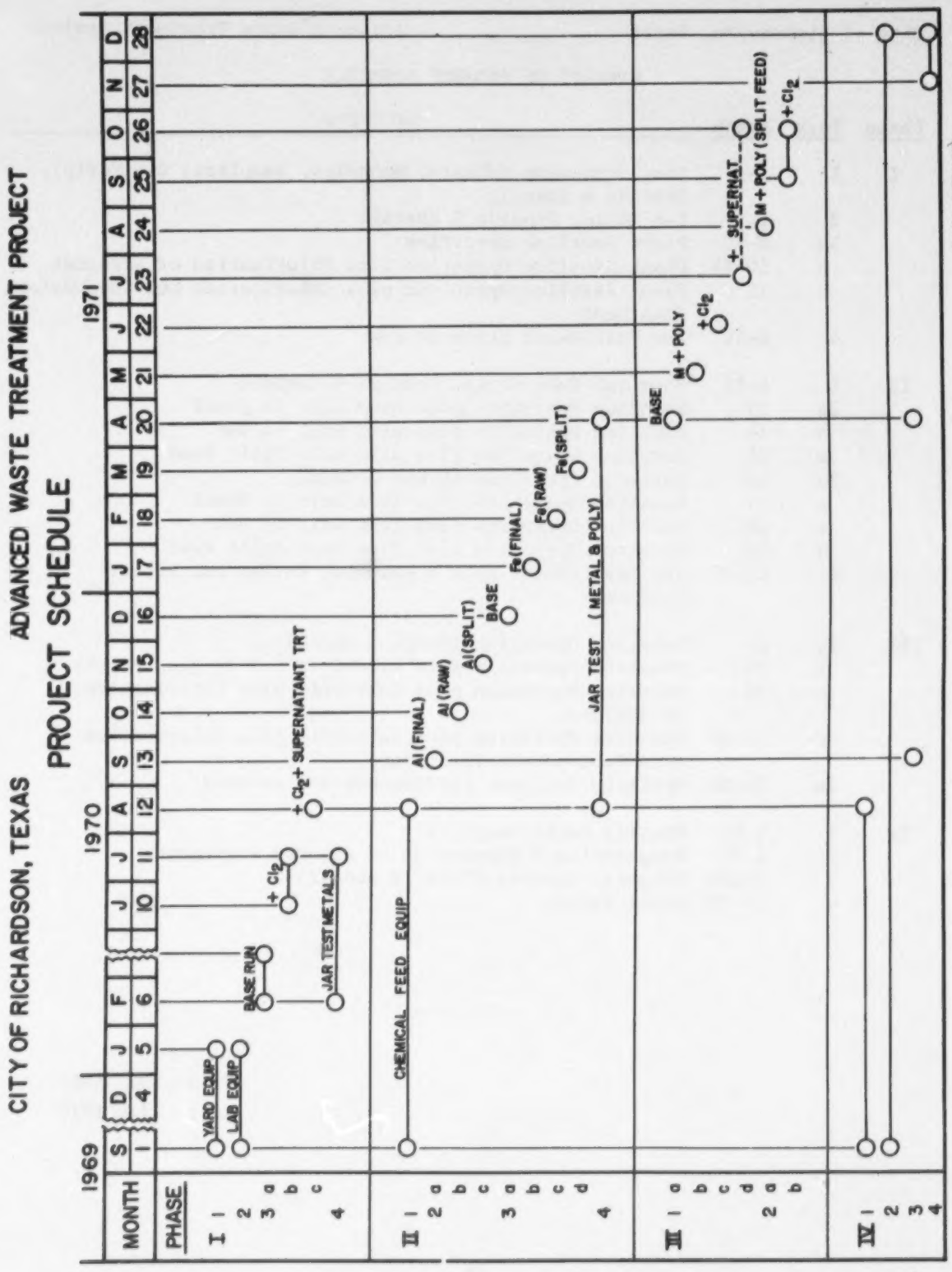
Construction labor and supervision were by city personnel, and figures cited include a factor for overhead. The high ratio of materials to labor relates to such expensive equipment as a $6,800 automatic chlorinator, two magnetic flow meters at a $4,200 cost, three fiberglass chemical tanks at $5,000 total, two polymer mixers at $2,200 total, and four chemical feed pumps at $6,800 total. All these items total $25,000 which is considerably more than it cost to install them.

Combining all facility costs related to providing chemical coagulation, a total outlay of $80,000 was required. This converts to $50,000 per MGD of plant capacity, but that unit cost figure could not be extended to estimate costs at other plants. For example, perhaps $60,000 would be required to outfit a 0.5 MGD plant, and $100,000 might outfit a 5 MGD plant. In other words, the basic equipment would cost about the same no matter what size plant is involved.

Operating costs for chemical coagulation consist almost entirely of chemical costs alone. Additional power might cost $200 or $300 per year. The existing operating staff can run the equipment. Control testing might require an additional analyst in the laboratory, but insufficient experience is available to verify this. Liquid alum costs 33¢ per pound of aluminum, delivered in Richardson. Making some broad assumptions regarding demand, alum costs might run 4¢ to 5¢ per 1000 gallons of water. This would total some $25,000 per year at this plant. No information is available now regarding efficiency or cost of ferric iron as a coagulant, nor has the role of polymers been studied.

In summary, construction costs for chemical coagulation are well defined for the Richardson facilities, but they might be quite different at another plant. It appears most of the operating costs would go to purchase coagulant, and some highly generalized figures have been offered to give some sort of perspective.

The projected activities are shown on this sheet. A written key on the following page gives more details on abbreviated entries.



City of Richardson, Texas — Advanced Waste Treatment Project

SUMMARY OF PROJECT SCHEDULE

Phase	Task	Month	Activity
I	1	1-5	Yard Equipment (Meters, Manholes, Samplers, Cl_2 Equip), Provide & Install
	2	1-5	Lab Equip, Provide & Install
	3a	6-9	Plant Baseline Operation
	b	10-11	Plant Baseline Operation plus Chlorination of Effluent
	c	12	Plant Baseline Operation plus Chlorination and Supernatant Treatment
	4	6-11	Jar Test Metal Salts on Raw
II	1	1-12	Chemical Feed Equip, Provide & Install
	2a	13	Baseline Operation plus Alum Salt in Final
	b	14	Baseline Operation plus Alum Salt in Raw
	c	15	Baseline Operation plus Alum Salt Split Feed
	3a	16	Baseline Operation (Purge & Check)
	b	17	Baseline Operation plus Iron Salt in Final
	c	18	Baseline Operation plus Iron Salt in Raw
	d	19	Baseline Operation plus Iron Salt Split Feed
	4	12-20	Jar Test (Metal Salt + Polymer) on Raw and Filter Effluent
III	1a	20	Baseline Operation (Purge & Check)
	b	21	Baseline Operation plus Salt-Poly Fed at Best Points
	c	22	Baseline Operation plus Salt-Poly plus Chlorination of Effluent
	d	23-26	Baseline Operation plus Salt-Poly plus Chlorination plus Supernatant Treatment
	2a	23-26	Optimize for best performance and economy
IV	1	1-12	Monthly Letter-Reports
	2	1-24	Preparation & Submission of Expense Statements
	3	13&20	Progress Reports (Phase I and II)
	4	27-28	Final Report

Orig: Oct 1969
Rev: Jul 1970

APPENDIX B DATA MATRIX

82

This sheet shows major items reported daily. All are calculated and recorded directly on Lab Bench Sheets, then transferred directly onto computer cards. A typical Bench Sheet (for ammonia nitrogen) is shown on the following page.

	RAW	PRIM EFF	FILT EFF	FINAL EFF	RECIRC	SLUDGE 1	SLUDGE 2	SLUDGE 3	RAW SUP 1	RAW SUP 2	RAW SUP 3	TREAT SUP	BED DRAIN	
FLOW	●				●	●	●	●	●	●	●	●	●	
TOT SOL	●	●	●	●	●	●	●	●	●	●	●	●	●	
TOT VOL SOL	●	●	●	●	●	●	●	●	●	●	●	●	●	
SUS SOL	●	●	●	●	●				●	●	●	●	●	
SUS VOL SOL	●	●	●	●	●				●	●	●	●	●	
SET SOL	●	●	●	●										
BOD	●	●		●					●	●	●	●		
DO	●			●										
COD	●	●	●	●	●				●	●	●	●	●	
PHOS	●	●		●	●	●	●	●	●	●	●	●	●	
TKN	●	●		●	●	●	●	●	●	●	●	●	●	
NH3	●	●		●		●	●	●	●	●	●	●	●	
NO2				●										
NO3	●			●										
ALK	●	●		●		●	●	●	●	●	●	●	●	
FE	●	●		●	●	●	●	●	●	●	●	●	●	
AL	●	●		●	●	●	●	●	●	●	●	●	●	
S	●					●	●	●	●	●	●	●		
SO4	●	●	●	●		●	●	●	●	●	●	●	●	
CL	●	●		●										
PH	●	●	●	●		●	●	●	●	●	●	●	●	
TEMP	●	●	●	●		●	●	●	●	●	●	●	●	
TURB	●	●		●										
COLI	●			●										
FECAL	●			●										

PARAMETER 14 (12) NH3

DATE (3 4 5 6 7)

STATION	ABSORBANCE	FACTOR	MG/SAMPLE	DILUTION	RESULTS	COMPUTER
RAW					— —•— —	25 26 27• 28
PRIMARY EFFL					— —•— —	29 30 31• 32
FILTER EFFL						33 34 35 36
FINAL EFFL					— —•— —	37 38 39• 40
RECIRC						41 42 43 44
SLUDGE 1					— — —•—	45 46 47 48•
SLUDGE 2					— — —•—	49 50 51 52•
SLUDGE 3					— — —•—	53 54 55 56•
RAW SUP 1					— — —•—	57 58 59 60•
RAW SUP 2					— — —•—	61 62 63 64•
RAW SUP 3					— — —•—	65 66 67 68•
TREAT SUP					— — —•—	69 70 71 72•
BED DRAIN					— — —•—	73 74 75 76
STANDARD					— — —•—	

425 mμ

APPENDIX C

DATA PROCESSING

Electronic data processing is used to handle the 140 items of data generated each day. There are two major programs: a daily report, and a statistical report. In the daily report the following items are printed out on one page:

1. Up to 23 parameters at each of 13 sampling stations
2. Five computed loadings at up to 12 stations, expressed in lb/day
3. Two ratios at 10 stations: BOD/COD, and SVS/Susp Solids
4. Six clarifier loadings: hydraulic, and solids
5. Four filter loadings: hydraulic, and organic
6. Two digester loadings: hydraulic, and volatile solids
7. Twelve percentages of removal: primary units, and overall

The statistical report comes from processing selected groups of daily reports, and each one-page printout considers one parameter (e.g. BOD) at all of the sampling stations. Printouts include:

1. Tally of number of occurrences
2. Max-Min values
3. Arithmetic mean, and standard deviation
4. SD/Mean
5. Mean $\pm$ SD
6. Mean $\pm$ 2SD
7. Five selected cumulative probability tables
   a. Group limits and plotting position
   b. Population within groups
   c. Exceedance within groups (95% gaussian normality)
   d. Cumulative frequency

CHEMICAL PRECIPITATION

Sidney A. Hannah

ADVANCED WASTE TREATMENT AND WATER REUSE SYMPOSIUM

South Central Region, FWQA

Dallas, Texas

January 12 - 14, 1971

CHEMICAL PRECIPITATION

Sidney A. Hannah

1. Historic

The recent interest in chemical precipitation for treatment of wastewater was preceded by a similar interest some sixty years ago. The Royal Commission of London (24) issued a report which endorsed the practice. The process was intended to replace primary sedimentation. Alum or lime was used to flocculate raw sewage to produce effluents with 10-40 mg/l of suspended solids. The practice was not widely adopted, however, because of the engineering difficulties and particularly because of the problems of handling the sludge.

The Guggenheim process proposed in the thirties also involved chemical precipitation but this also failed to be widely adopted. Possibly, a dominant reason for the failure of adopting chemical precipitation at that time, aside from the extra cost, engineering and sludge problems, was the lack of pressure to produce a better effluent.

2. Objectives of Chemical Precipitation

The impetus to use chemical precipitation is provided by the need to remove phosphorus. But chemical precipitation, while removing phosphorus, also removes in excess of 95 percent of the suspended solids yielding a fully clarified effluent with 95 percent of phosphorus removed or in precipitated form.

Conventional treatment techniques of settling and biological oxidation are capable of removing some phosphorus as shown in Fig. 1. In spite of some encouragement that certain plants are capable of greater removals, the most that can be expected in general are 5-15 percent by sedimentation, 20-30 percent through a trickling filter and up to 50 percent by activated sludge. Moreover, actual phosphorus removal will ultimately depend on the amount of sludge permanently removed from the process stream. This means that phosphorus concentrated in the sludge must be removed from digester contents.

FIGURE 1 Phosphate Removal by Conventional Waste Treatment Plants

Type of Treatment Plant	% Phosphorus Removal
Primary Sedimentation	5-15
Primary and Trickling Filter	20-30
Primary and Activated Sludge	30-50

The most economic and reliable method of removing phosphorus and suspended solids is chemical precipitation. The choice of point of addition depends on several factors which are shown in Fig. 2. Chemicals may be added to raw sewage with separation of solids occurring in the primary, to the aerators with separation obtained with the biological sludge, or chemicals may be added to the final clarifier as a tertiary process. All of these variations have been studied and are technically feasible.

A choice also has to be made on the chemical to use. The factors to be considered here are shown in Figure 3. The influent phosphorus level and particularly the permissible residual phosphorus are important considerations. Wastewater characteristics determine in part the chemical dosage and finally, facilities for sludge handling and ultimate disposal of the sludge must be considered.

A variety of chemicals can be used for chemical precipitation. These are shown in Fig. 4. Various salts of iron are equally effective. These salts include ferrous chloride or ferrous sulfate, ferric chloride or ferric sulfate, and waste pickle liquor which is a waste product from steel processing and consists of largely ferrous chloride or sulfate with some ferric salts. Lime or sodium hydroxide must be added with the ferrous salts. The pH of optimum precipitation with the latter appears to be around pH 8.0.

Aluminum salts may also be used. Commercial alum, aluminum sulfate, is the more common although sodium aluminate has also been used. The latter, while more expensive, has the advantages of containing some excess caustic which helps to maintain pH and does not add sulfate ion, as alum does.

Lime as a precipitant is very attractive because of its cheap initial cost and because sludge can be calcined to recover reuseable lime while at the same time incinerating the organic sludge.

All of the metal precipitants may require the addition of polymer to obtain effective settling and separation of solid from liquid.

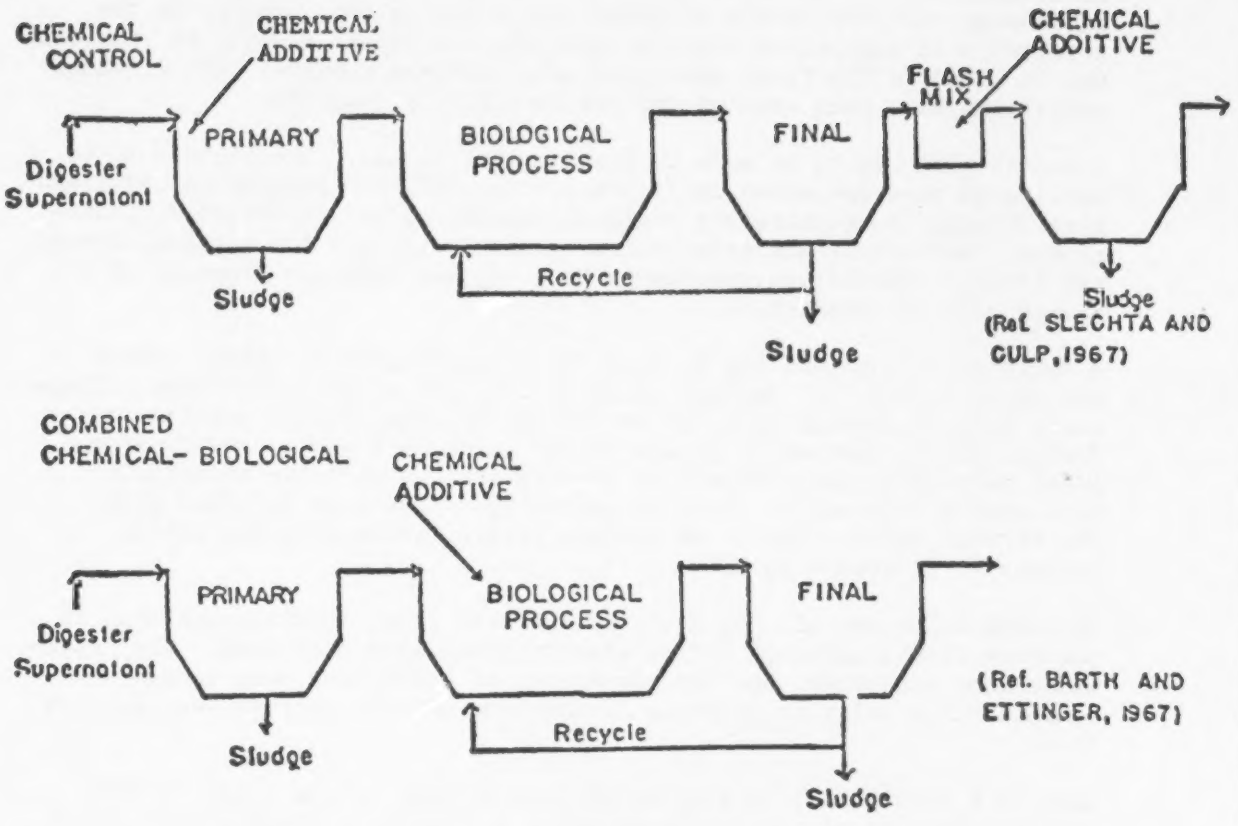


Figure 2 PHOSPHORUS CONTROL BASIC SYSTEMS

Figure 3

FACTORS AFFECTING CHOICE OF CHEMICALS

1. INFLUENT PHOSPHORUS LEVEL
2. EFFLUENT DISCHARGE STANDARD
3. WASTEWATER CHARACTERISTICS
4. PLANT SIZE
5. CHEMICAL COSTS INCLUDING TRANSPORTATION
6. SLUDGE HANDLING FACILITIES
7. SLUDGE DISPOSAL FACILITIES
8. OTHER PROCESSES UTILIZED

Figure 4 Alternative Chemical Systems for Phosphorus Removal in the Primary

A. Iron

Ferrous Chloride or Sulfate - Base - W/O* Polymer

Commercial or Waste Pickle Liquor — Lime or Sodium Hydroxide

Ferric Chloride or Sulfate - W/O Polymer

B. Aluminum

Alum or Aluminate - W/O Polymer

C. Lime - W/O Additives

1 or 2 Stage

*W/O - With and Without

3. Performance Results

(a) Precipitation with iron salts

All of the chemicals mentioned and all of the points of addition have been tested at full scale. These tests provide the information for any plant to determine the choice of chemical and point of addition using the factors pointed out in Fig. 2 as the basis for decision.

The addition of metallic salts to primary clarifiers not only removes phosphate but obtains clarification thus providing suspended solids, BOD-COD and phosphate removal all at the same time. Thus, the organic load to the secondary system is reduced with possible reduction in air requirements and waste activated sludge production.

The results of full-scale chemical treatment at Grayling, Michigan, are shown in Figure 5. Without chemicals, removal in the primary amounted to 50% for SS and 41% for BOD. No removal is reported for phosphorus, although I suspect that some removal was obtained. Adding 15-30 mg/l of iron as ferrous chloride increased SS removal to 78 percent, BOD removal to 58 percent and 72 percent of the phosphate was precipitated. Note that with ferrous salts, sodium hydroxide at the rate of 30-50 mg/l as $CaCO_3$ had to be added. Most chemical precipitation requires polymer for effective clarification. In this case 0.3-0.5 mg/l was used.

A similar use of ferrous salt was tried at Mentor, Ohio, Fig. 6. In this case waste pickle liquor was used as the source for ferrous chloride. Waste pickle liquor was added at a dosage to yield 43 mg/l as Fe. Lime, rather than caustic, was added at the rate of 66 mg/l. Again polymer was required - 0.4 mg/l. Removals of SS and BOD were similar to the Grayling test but phosphate removal was superior amounting to 83.5 percent. The greater phosphate removal can be accounted for by the greater iron dosage. Removals in excess of 90-95 percent can be obtained with even greater iron dosages and careful separation of the precipitated phosphate. The two forms of pickle liquor are apparently interchangeable. Ferrous sulfate was successfully used at Texas City. When available within reasonable hauling distances, waste pickle liquor containing 6-9 percent of ferrous iron can be an inexpensive source for iron. The hauling costs amounted to 1.5¢/lb of Fe at Texas City and 2¢/lb Fe at Mentor. The cost of lime or sodium hydroxide must be considered. Also, the ferrous iron must be oxidized to ferric form to obtain removal of both phosphate and iron, hence sufficient oxygen must be present. Theoretical work with ferrous iron in a contract with Atomics International has shown that the optimum pH centers around pH 8.0.

The need to control pH and to ensure availability of oxygen to prevent excessive soluble ferrous compounds in the effluent has tended to diminish

Figure 5 RESULTS AT GRAYLING, MICHIGAN

CHEMICALS:

$FeCl_2$ = 15-30 mg/l as Fe

NaOH = 30-50 mg/l as $CaCO_3$

A-23 = 0.3-0.5 mg/l

	WITHOUT CHEMICALS (10 weeks)			WITH CHEMICALS (10 weeks)		
	Raw mg/l	Pri.Eff. mg/l	% Rem.	Raw mg/l	Pri.Eff. mg/l	% Rem.
SS	157	78	50	224	50	78
BOD	170	101	41	178	74	58
TOTAL P	No removal			15.5	4.4	72

Figure 6 RESULTS AT MENTOR, OHIO

CHEMICALS:

WASTE PICKLE LIQUOR ($FeCl_2$) = 43 mg/l as Fe

LIME = 66 mg/l

A-23 = 0.4 mg/l

PERCENT REMOVAL WITH CHEMICALS

SS = 74%

BOD = 59%

TOTAL P = 83.5%

the advantages of the low cost ferrous iron. For these reasons ferric chloride has been more widely accepted. Full-scale testing with ferric chloride and polymer in the primary is being conducted at Grand Rapids, Michigan, at Benton Harbor, Michigan, and elsewhere.

Addition of chemicals to the primary and increased capture of organic solids clearly indicate that more sludge solids will have to be handled. Good quantitative data on this aspect are lacking although the study at Grand Rapids should be informative. Some data were obtained at Benton Harbor, Michigan, Fig. 7. The study was conducted in three stages; a baseline period with no chemical addition; a second period when ferric chloride and polymer were added but with wasting of activated sludge to the primary, and a third period when chemicals were added but waste activated sludge was not cycled to the primary. The plant uses the "Kraus Process" which involves returning a reaerated portion of the waste activated solids to the primary.

Chemical addition actually reduced the volume of sludge pumped but the solids content increased from 3.8 to 4.82 percent with chemical addition and no recycle. With increased organic removal, dissolved oxygen in the aeration tank increased from 4.8 to 6.6 mg/l. This benefit is obscured by the increased air supplied to the tank.

The presence of chemical sludge posed no problem in the digesters. With increased organic solids pumped to the digester, total gas production increased. Gas production per pound of solids also increased from 3.48 ft^3/lb to 3.67 ft^3/lb. Operation was otherwise normal. A point worth mentioning here is that soluble phosphate concentration in the digester supernatant return flow was very low.

(b) Precipitation with aluminum salts

Either alum or sodium aluminate can be used for precipitation in the primary but has been little used for this purpose. Aluminum salts have been used as a chemical precipitant in the aerator. This aspect is discussed by another speaker. One reason why alum has not been so widely used in raw sewage clarification is its higher cost over iron salts. Sludge from iron precipitations are easier to handle than alum sludges. Alum, nevertheless, is widely used in Sweden in raw sewage flocculation because of the much lower cost of commercial alum in Sweden.

If very high quality effluent is required for discharge or reuse, treatment of the final effluent or tertiary treatment may be necessary. Both iron or aluminum salts can produce an effluent low in phosphorus, BOD and suspended solids. Alum, rather than iron salts, was chosen for the

Figure 7 Plant Data at Benton Harbor Using Ferric Chloride

	No Chemical Addition	Chemical Addition	
		Recycle to Primary*	No Recycle*
Primary Clarification			
Volume Pumped, Gal/Day	53,200	51,600	46,100
Solids Concentration,	3.80	4.29	4.82
Percent Volatile	64	63	60
Mixed Liquor Data			
Suspended Solids, mg/l	2500	2700	2400
Sludge Volume Index	85	78	64
Dissolved Oxygen	4.8	5.9	6.6
Air Applied, cfm	4480	4940	4710
Digester Operation			
Gas Production - ft^3	37,800	44,400	40,800
Gas Production - ft^3/lb of solids	3.48	3.82	3.67

*With and without Recycling of Waste Activated Sludge

400 gpm plant at Nassau County, New York. The objective of this study is to determine the feasibility of treating secondary effluent to a quality suitable for ground water discharge. In this instance, iron could not be used. The processes include, alum clarification, dual media filtration, and adsorption on granular activated carbon. Fig. 8 shows results of operation of the clarification and filtration portions of the systems. With an average alum dose of 200 mg/l, phosphorus was reduced to 1.4 mg/l in the clarifier effluent. It is significant that filtration produced a highly clarified effluent containing 0.08 mg/l P and 0.2 JTU turbidity. The filter served to capture the precipitated phosphates that did not settle in the clarifier. An important observation is that when sufficient chemical is added to obtain good clarification, good phosphorus removal is also obtained.

Figure 8 NASSAU COUNTY OPERATING RESULTS

CONSTITUENT	INFLUENT	CLARIFIER EFFLUENT	FILTER EFFLUENT
POLYPHOSPHATE, mg/l P	0.5	-	-
TOTAL PHOSPHATE, mg/l P	7.2	1.4	0.08
TURBIDITY, JTU	50	6	0.2

The quality of secondary effluents can be considerably increased by chemical precipitation and sand filtration. Some work done by the Water Pollution Research Laboratory in England on two treatment plants is summarized in Fig. 9. All parameters of product quality were substantially reduced. Final effluent contained 2-5 SS, 2-3 BOD, 1.5-0.15 phosphate and turbidity 0.8 to 3.5 units. Soluble aluminum ranged 0.1 to 0.45 mg/l.

FIGURE 9

TREATMENT OF EFFLUENTS OF POOR QUALITY

BY CHEMICAL COAGULATION AND SAND FILTRATION

mg/l unless otherwise stated	Effluent A		Effluent B	
	Initial	Final	Initial	Final
SUSPENDED SOLIDS	84	2	26	5
BOD	35	2	25	3
COD			83	26
PHOSPHATE	11	1.5	2.5	0.15
ALUMINUM		0.1		0.45
COLOR (HAZEN UNITS)	90	33	42	27
TURBIDITY (ATU)		0.8		3.5

(c) Lime precipitation

The chemistry of lime precipitation is entirely different from the chemistry of iron or aluminum. With the latter the dose is related to phosphate content and the requirement to provide sufficient hydrolysis products of the metal. In practice these requirements have been met with dosages of alum or iron ranging from 150 to 300 mg/l. These dosages will generally produce a clarified effluent low in phosphorus. Lime dosage, on the other hand, is more dependent on the wastewater characteristics, principally alkalinity and hardness. In practical terms the dosage is determined by the pH required to obtain the desired clarification and phosphorus removal. When slaked lime $Ca(OH)_2$ is added to wastewater, it reacts with alkalinity precipitating calcium carbonate; it reacts with orthophosphate to precipitate hydroxyapatite, $Ca_5(OH)(PO_4)_3$. Precipitation of magnesium hydroxide begins around pH 10 and is complete at pH 12.

The amount of lime required to raise the pH to a given value is a function of the initial alkalinity. This relationship is shown in Fig. 10. Wastewaters with high alkalinity (buffer capacity) necessarily require high doses to reach a pH range where phosphorus precipitation is effective. The higher the alkalinity, the greater the lime requirement. The pH range that must be obtained for high phosphorus removal is about pH 10 to 11. At these pH's residual total phosphorus will range around 0.1 to 0.3 mg/l. This relationship is shown in Fig. 11. Looking at Fig. 10 again, the lime dose to obtain pH 10 can range from as little as 50-75 mg/l for a wastewater with an alkalinity of 22 mg/l to almost 400 if the alkalinity is 600 mg/l.

The two extremes of lime clarification in high and low alkalinity waters can be illustrated by the operation of the pilot plants at Lebanon, Ohio, and Blue Plains at Washington, D.C. A pilot plant at Lebanon, Ohio, treats secondary effluent with lime and media filtration. This wastewater has a relatively high hardness and alkalinity. Operation at pH 10.7 resulted in a phosphorus concentration of 0.5 mg/l and 0.1 mg/l in the clarifier and filter effluents respectively. The lime requirement has ranged from 300-400 mg/l. Because of the relatively high hardness at Lebanon, a sufficient portion of the sludge consisted of dense calcium carbonate which settles readily, thus the entire operation can be conducted in a single stage.

Lime clarification at the Blue Plains pilot plant where the wastewater is low in both hardness and alkalinity must be operated either as a two-stage system or a single-stage with the addition of carbonate as soda ash or CO_2. There is insufficient alkalinity to permit the formation of a dense, good settling calcium carbonate sludge with lime addition alone. The most effective treatment sequence has been a two-stage process; lime to pH 11.5 in the first-stage clarifier, reduction of pH to 9.5-10.0 by addition of CO_2 and clarification in the second stage with the aid of 6-12 mg/l Fe^{+++}. Results obtained with single-stage

FIGURE- 10

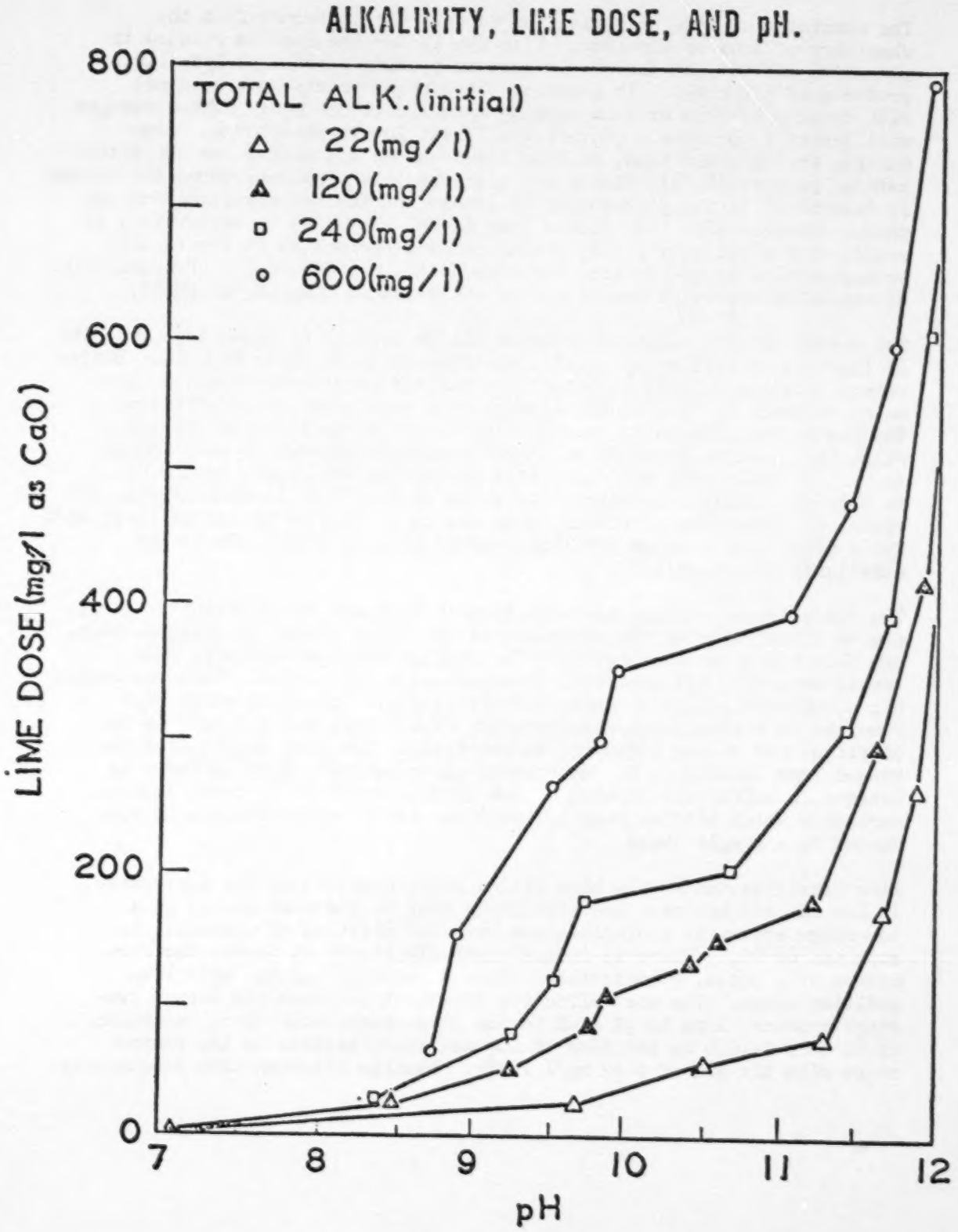
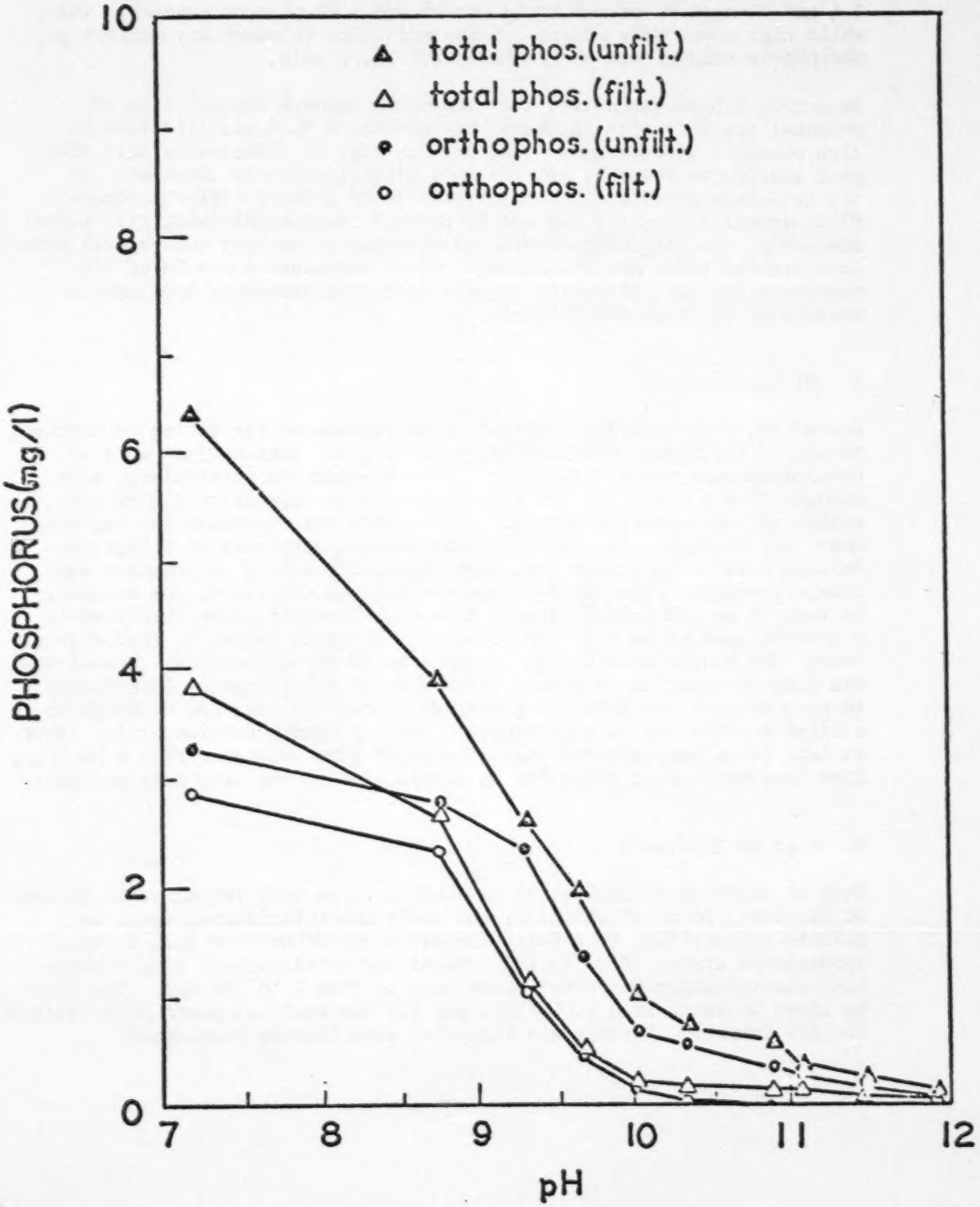

ALKALINITY, LIME DOSE, AND pH.
TOTAL ALK.(initial)
22(mg/l)
120(mg/l)
240(mg/l)
600(mg/l)
LIME DOSE (mg/l as CaO)
800
600
400
200
0
7
8
9
10
11
12
pH

FIGURE 11

LIME PRECIPITATION AND PHOSPHORUS REMOVAL FROM RAW WASTEWATER.



and two-stage lime clarification are shown in Fig. 12. In the two-stage process 350-400 mg/l as CaO was added to obtain a pH of 11.8-12.0. For the single-stage process 250 mg/l of lime was added to a pH of 9.5. Both processes achieved a residual P content after media filtration of 0.4 and <1 mg/l P, respectively, or 96 and > 89 percent removal. Thus, while high alkalinity waters require more lime to reach any desired pH, phosphorus removal can be obtained with lower pH's.

Thus far, I have emphasized the phosphorus removal capabilities of chemical precipitation and have only mentioned that clarification is also obtained concurrently. The data in Fig. 12 illustrates that with good phosphorus removal, equally good clarification is obtained. In the two-stage process, lime clarification of primary effluent obtained 67.6 percent removal of COD and 75 percent removal following filtration. Similarly, the single-stage process obtained 65 percent COD removal after lime precipitation and filtration. These excellent removals of COD by precipitation and filtration compare well with secondary treatment of wastewater by trickling filters.

4. Sludge Handling

One of the more important factors to be considered for choice of chemical to use is the sludge handling characteristics. This subject will be covered in more detail elsewhere. Iron sludges and particularly alum sludges from a clarifier are likely to contain only about 0.5 percent solids and will dewater slowly. Hence costs for concentrating and disposal may be high. In contrast, lime sludge, particularly sludge containing calcium carbonate from high alkalinity waters is granular and dewaters easily. Lime sludge from the Lebanon operation, for example, is removed as a 3 percent slurry from the clarifier, then thickened in a gravity settler to a 15 percent slurry which is pumped to sand drying beds. The sludge dewaters on the beds to 50 percent solids. Dewatering can also be obtained on vacuum filters or by centrifuges. In contrast to alum or iron for which no practical method for recovery of metal is available, lime can be recalcined to recover useful calcium oxide. Work at Lake Tahoe demonstrated that recalcined lime recovered from a tertiary lime treatment is as effective as virgin lime in the treatment process.

5. Cost of Treatment

Cost of chemical precipitation is subject to so many variables as choice of chemical, point of addition, and waste characteristics, etc., as pointed out earlier, that this discussion can do no more than indicate approximate costs. Fig. 13 illustrates the total cost of single-stage lime clarification for plant sizes ranging from 1 to 250 mgd. The cost is shown to range from 6.09¢/1000 gal for the smallest plant to 3.78¢/1000 for the largest. Savings are indicated when lime is recalcined.

Figure 12 Results of Treatment by Lime Clarification, Filtration and Carbon Adsorption of Primary Effluent at Washington, D. C. — (I) and Lebanon, Ohio (II)

	Two-Stage Lime Clarification - Low Alkaline Wastewater(I)		Single-Stage Clarification - High Alkaline Wastewater(II)	
	mg/l	% Removal	mg/l	% Removal
Primary Effluent				
Phosphorus, P	10.4		8.8	
TOC	78.4		76	
BOD	139		76	
COD	265		192	
Lime Clarified Effluent				
Phosphorus, P	0.5	94.8		
TOC	27.1	65.2		
BOD	42.0	69.7		
COD	86	67.6		
Filtered Effluent				
Phosphorus	0.39	96.2	< 1	> 89
TOC	22.6	69.9	26	52.3
BOD	28	80.0	25	67.2
COD	66	75.0	67	65.0
Carbon Effluent				
Phosphorus	-		< 1	> 89
TOC	6.5	90.6	10	87
BOD	4	97	10	87
COD	11	95.8	27	86

Figure 13 Total Cost of Phosphate Removal for Single-Stage Lime Clarification

(Cents per 1,000 gallons)

	Size of Plant			
	1 mgd	10 mgd	100 mgd	250 mgd
Capital amortization	1.25	1.12	.84	.77
Land amortization	.12	.12	.12	.12
Operating and maintenance	2.30	.79	.50	.47
Cost of chemicals				
Lime	1.75	1.75	1.75	1.75
Cost of sludge disposal by hauling to land fill (25-mile one-way trip)	.67	.67	.67	.67
TOTAL	6.09	4.45	3.88	3.78
Savings if lime can be reclaimed	-.67	-.67	-.67	-.67
TOTAL (with recalcining)	5.42	3.78	3.21	3.11

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